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# Use of Nutrient Balances in Comprehensive Watershed Water Quality Modeling of Chesapeake Bay

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Aqua Terra Consultants

Patrick N. Deliman, WES

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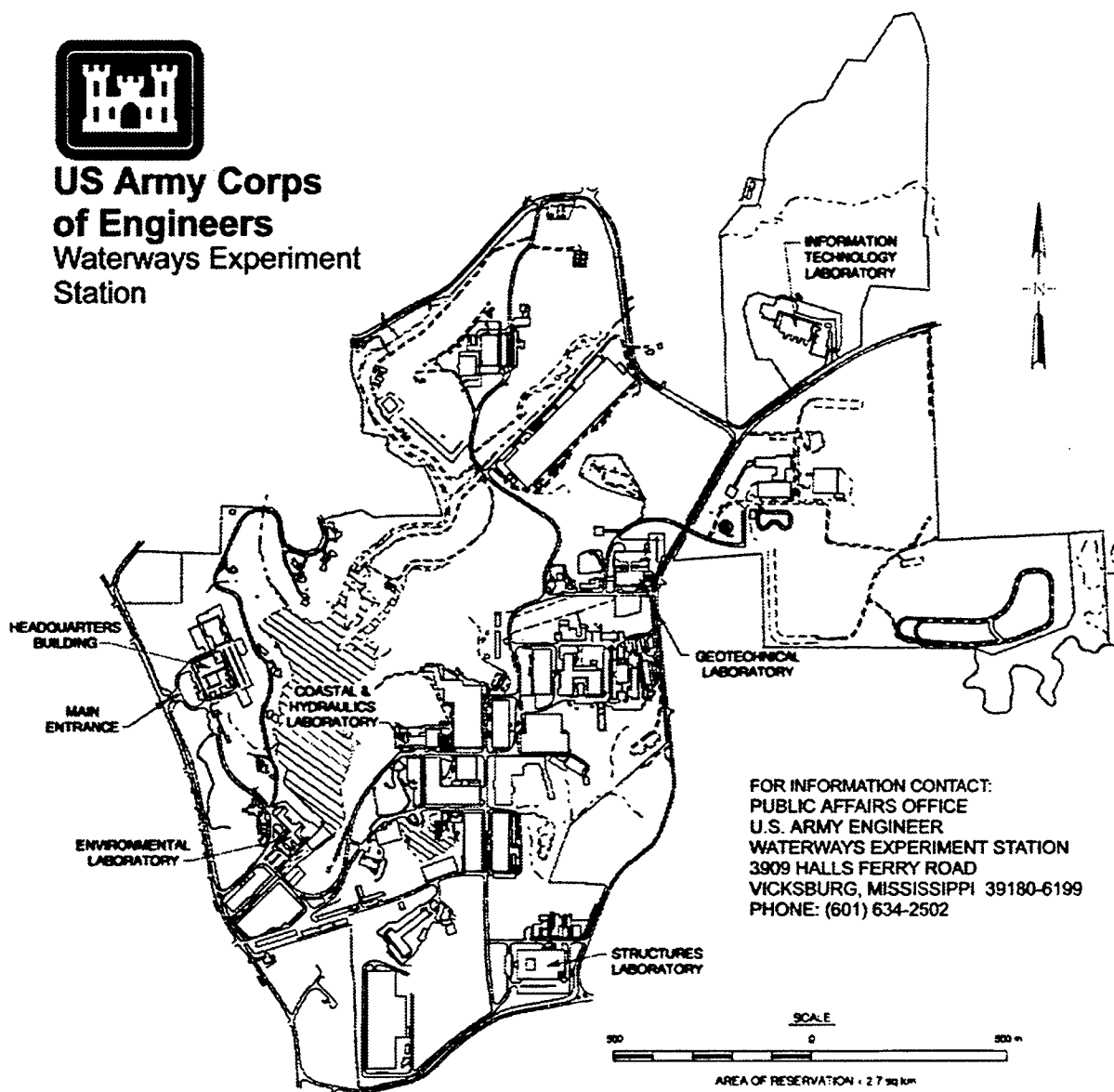
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# Preface

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The work herein was authorized under U.S. Army Engineer Waterways Experiment Station (WES) Contract No. DACW39-94-C-0052 with Aqua Terra Consultants, dated 30 March 1994 and amended 25 July 1995; the work was completed on 30 September 1996.

Dr. Patrick N. Deliman, Environmental Laboratory (EL), WES, was the Project Officer and co-author of this report. He was instrumental in facilitating the administration and execution of the contract work.

The Use of Nutrient Balances in Comprehensive Watershed Water Quality Modeling of Chesapeake Bay study, as documented in this report, was performed for the U.S. Environmental Protection Agency Chesapeake Bay Program Office (CBPO), Annapolis, MD. Mr. Lewis Linker, CBPO, was point of contact. The CBPO provided data for model testing and refinement within the Chesapeake Bay Watershed Model that were critical to the successful completion of this study. Mr. Linker and his staff at the CBPO are acknowledged for their assistance and cooperation.

Mr. Anthony S. Donigian, Aqua Terra, was the Principal Investigator and Project Manager, responsible for the overall technical direction of the work and preparation of the final report. Mr. Radha V. Chinnaswamy, also of Aqua Terra, reviewed the literature and assisted in developing nutrient balances for the simulated land-use categories; he also performed model testing and calibration and assisted in preparing the final report. Messrs. Brian Bicknell and Thomas Jobs, Aqua Terra, assisted with operational and technical model application issues throughout the study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin, and EL Director was Dr. John Harrison. Dr. Richard E. Price was Chief, Environmental and Effects Division, EL. WES Commander was COL Robin R. Cababa, EN.

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# Conversion Factors, Non-SI to SI Units of Measurement

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Non-SI Units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	2.471	hectares
cubic feet	0.02831685	cubic meters
Fahrenheit degrees	5/9	Celsius degrees <sup>1</sup>
feet	0.3048	meters
inches	2.54	centimeters
pounds (mass)	0.4535924	kilograms
square miles	2.590	square kilometers
<sup>1</sup> To Obtain Celsius (C) temperature from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F-32)$ .		

# 1 Introduction

---

## Study Background

In 1987 the Chesapeake Bay Agreement was signed by the EPA Administrator and governors of the member states recommending a 40% reduction in nutrient loadings to the Chesapeake Bay to restore and maintain the water quality and living resources of the Bay. The Chesapeake Bay Watershed Model, based on the U.S. EPA Hydrologic Simulation Program-Fortran (HSPF) (Bicknell et al. 1993) was used to provide a framework for quantifying and evaluating the needed nutrient loading reductions to the Chesapeake Bay, and to allow the Chesapeake Bay Program Office (CBPO) to evaluate the impacts of land use changes and alternate nutrient and agricultural management practices. The Watershed Model provides total pollutant loadings from all land areas tributary to the Bay in order to drive a fully dynamic three-dimensional, hydrodynamic/water quality model of Chesapeake Bay.

The CBP Watershed Model is a unique state-of-the-art watershed modeling capability that includes detailed soil process simulation for agricultural areas, linked to an instream water quality and nutrient model capable of representing comprehensive point and nonpoint pollutant loadings for the entire 68,000 square mile drainage area of the Chesapeake Bay. In 1992, major refinements and re-calibration of the Watershed Model was completed and a report prepared describing the CBP Phase II Watershed Model application to the Bay drainage for calculating nutrient loadings to the Bay (Donigian et al. 1994). That work included updating and extending the model database, incorporating detailed agricultural process simulation using the AGCHEM modules of HSPF, developing capabilities for instream sediment-nutrient interactions, and re-calibrating the improved model for the extended time period. However, for non-agricultural areas, simple empirically-derived algorithms were used to estimate nonpoint loadings, both surface and subsurface, based on user-derived potency factors, washoff rates, and subsurface concentrations. This approach for the non-agricultural lands, including the large areas of forested lands, did not maintain a nutrient balance and inhibited detailed assessment of the impacts and contributions of atmospheric pollutant sources (specifically nitrogen) to overall water quality.

## Scope and Objectives

Recent HSPF code enhancements (Bicknell et al., 1996a) have extended the detailed AGCHEM algorithms to forested areas (Hunsaker et al, 1994; Bicknell et al., 1996b), have added more direct input of atmospheric sources, and have improved the AGCHEM plant uptake functions for better representation of agricultural nutrient management practices (Donigian et al., 1995). These

enhancements have shown the added benefits of performing detailed nutrient balance calculations for the non-agricultural areas. As a result of these efforts, additional improvements and refinements were identified and recommended to more directly consider atmospheric deposition and other nutrient sources by allowing nutrient balance approaches for **all** land uses, consistent with the recommendations of the Chesapeake Bay Executive Council and the Nonpoint Source Evaluation Panel in 1990 (Chesapeake Bay Nonpoint Source Evaluation Panel, 1990). This comprehensive nutrient balance approach will help improve the overall utility of the Watershed Model as a planning tool for comprehensive watershed planning and assessment of nutrient management/reduction alternatives.

The specific improvements recommended and tasks identified in this effort include the following developmental and application aspects:

#### **Model Development and Refinement**

- Develop nutrient balances and simulation procedures for the AGCHEM module to better represent nutrient cycling, mass balance, and runoff contributions for non-agricultural lands
- Test the AGCHEM procedures and refinements on the non-agricultural land uses, along with atmospheric sources, for selected segments of the CBP Watershed Model

#### **Model Testing and Application**

- Apply the refined AGCHEM procedures for the non-agricultural lands to a selected subbasin of the Chesapeake Bay drainage
- Re-calibrate the Watershed Model, with the refined AGCHEM, for the selected subbasin and assess the load contributions from all sources and the impact of the refined procedures

We selected the Shenandoah River subbasin within the Chesapeake Bay drainage to fully test the refined AGCHEM module integrated within the Watershed Model framework. Figure 1 shows the CBP Phase III Watershed Model segmentation for the Above Fall Line (AFL) region, along with the location of the Shenandoah subbasin. The most recent land use, point source, meteorologic, atmospheric deposition, septic system load, flow, and water quality data used in the current Phase IV watershed model effort was provided by the Chesapeake Bay Program Office (L. Linker, personal communication, 1996).

## **SUMMARY CONCLUSIONS AND RECOMMENDATIONS**

The water quality results from this effort are not greatly different from those produced in the earlier study, in spite of all the changes implemented, including more extensive application of AGCHEM, addition of septic system loads, refinement of loading rates, and additional calibration. However, this simply indicates that the prior calibration was a good representation of the observed data, and that the changes implemented to better define the load sources were incorporated while maintaining the accuracy of the overall simulation. The real benefits of the current refinement phase of the CBP

## AFL Model Segments

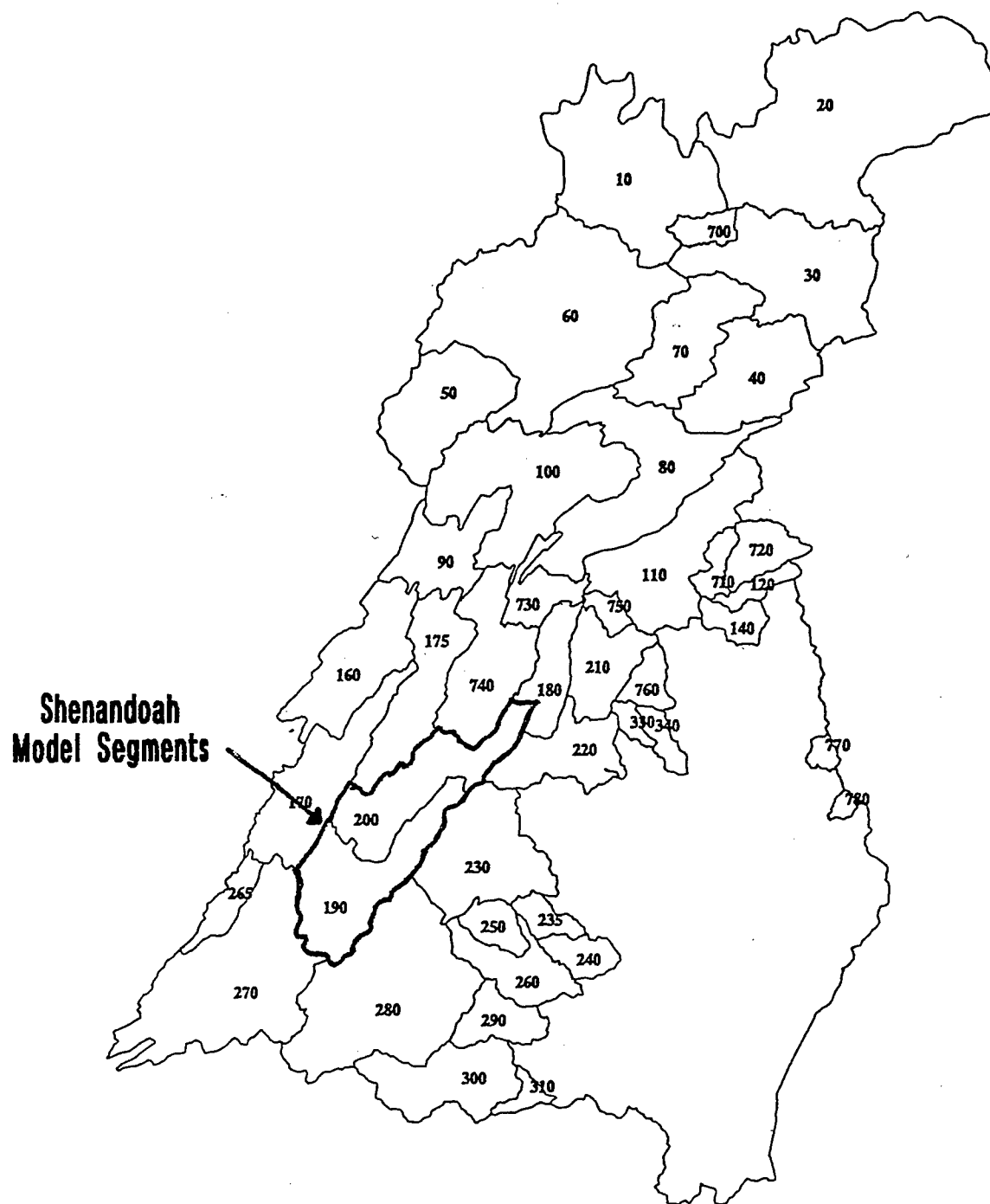


Figure 1. Chesapeake Bay Watershed Model and Shenandoah Model Segments

Watershed Model are realized from the extension of the nutrient balance approach to all major land use (except urban, in our simulations), and the utility of this approach for nutrient management.

Below we discuss some of the areas where the current results differ from those presented earlier in Donigian et al (1995), and identify some problems that still remain for selected constituents, where further 'fine tuning' of the calibration is recommended:

- a. The  $\text{NO}_3\text{-N}$  simulation is acceptable but not as seasonally correct as the earlier results reported by Donigian et al (1995). We suspect that the differences primarily in late summer, fall, and winter for selected years are due mostly to the newly-added septic loads and possibly inaccuracies in the seasonal loadings from the forest and pasture segments, i.e. the added AGCHEM segments.
- b. Both the  $\text{NH}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  simulations have improved with reduced contributions from cropland (along with reduced sediment loads), reduced peaks due to nutrient application adjustments, and increased algal uptake due to higher benthic algae levels than in the previous efforts.
- c. Simulation of both Organic N and Organic P has improved in this effort, and since Organic P is the major component of Total P similar improvement is shown there. Except for the November 1985 storm, the organics are generally well represented, although many of the peaks are still somewhat high. The improvements result from reduced sediment loads (and associated organics), adjustments to the N/P ratios, changes to manure applications, and reductions in phytoplankton levels (which are included in the organic state variables).
- d. With the detailed AGCHEM simulation of forests, the forest segment is now a major contributor of organic N, both labile and refractory in both dissolved and particulate forms, along with the animal acres segment. Also, for the forest segment, BOD and Organic P loads are calculated from the organic N components; thus BOD loads from forest are also a major component. In the Shenandoah, our results indicate that forests contribute about 25% of the Organic N load and 30% of the BOD load, while the animal acres segment contributes more than 30% of the Organic N to the stream. Both of these components need further investigation as there is little data to confirm this level of contribution.

Our primary recommendations resulting from this effort are as follows:

1. Finer segmentation for all stream reaches should be pursued as a major component of future Watershed Model enhancements. Increasing the spatial detail of the model by about a factor of 10x, along with appropriate detail in the precipitation and land use inputs, will help to improve all the process simulations, with specific benefits for the sediment and associated constituents, and benthic processes.
2. A more consistent approach for both BOD and organics loading needs to be developed and applied consistently across all land use categories. Currently the forest simulation enhancements provide loadings of both labile and refractory organic N components (dissolved and particulate), while the other AGCHEM segments (Hi-Till, Lo-Till, Hay, Pasture) are restricted to just the refractory particulate organic N and P eroded from the land surface. The

forest organic N capabilities can, and probably should, be applied to all land segments to implement this consistent loading representation. Further investigation of partitioning and transformation parameters for the organics will be needed, along with consideration of extending the forest N simulation approach to include phosphorous (see #8, below).

3. The current representation of septic system loads needs to be re-evaluated. The use of a constant load has helped to reduce the seasonality of the  $\text{NO}_3$  simulation shown in both the observed data and the previous model simulations. A revised approach is needed to allow the septic loadings to be 'hydrologically-driven' so that the seasonality of the hydrologic regime and loadings is represented.
4. The algal simulation, both phytoplankton and benthic algae, need more data, investigation, and evaluation. In this effort, the benthic algal levels were increased dramatically, by factors of 10 to 20, based on very limited data from widely scattered sites outside the Chesapeake Bay drainage. Additional literature data should be identified and actual site-specific data within the Chesapeake Bay watersheds collected to confirm the general magnitude of both the benthic and phytoplankton levels represented in the model. The algal simulation has such a critical impact on inorganic nutrient levels that major improvements in their modeling will depend on establishing realistic levels for the algal populations.
5. The urban land use should be divided into separate urban categories -- residential, commercial, industrial -- each with pervious and impervious fractions, as a prelude for nutrient mass balance and AGCHEM-type model application. Although CBPO has pursued an AGCHEM approach for the aggregated urban pervious segment, we feel a better definition of specific urban activities is needed to develop reasonable nutrient balances.
6. The CBPO should explore the option of eliminating the current 'composite crop' representation in the model, developed as part of the Phase II enhancements in 1991, and move to simulating each major crop individually in each cropland category. Recent computer hardware developments have eliminated many of the run time restrictions that required this simplification, and such an approach would allow more accurate representation of agricultural practices and the resulting nutrient balances.
7. In conjunction with representing each major crop, the nutrient application rates, timing, procedures, and composition distribution (both fertilizers and manure) should be closely reviewed and revised as needed. Experience with both the Watershed Model and the detailed Patuxent Model has confirmed the critical importance of the assumptions underlying the nutrient applications in the model.
8. The forest N simulation approach should be extended to include the P cycle, so that both N and P mass balances can be implemented for all land segments. Just as the previous AGCHEM module provided a valid framework for the forest N enhancements, the P cycle processes currently in AGCHEM can be readily adapted for forested conditions. Field site testing on small forested watersheds would be needed to fully evaluate the code enhancements.

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## **Format of this Report**

Following this introduction, Chapter 2 describes the development of nutrient balances for all land uses with the focus on the non-agricultural cropland segments while Chapter 3 presents the results of model testing and re-calibration to the Shenandoah subbasin. The Appendix includes complete simulation results for the Shenandoah subbasin..

## 2 Expected Nutrient Balances by Land Use Categories

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### Overview and Summary Tables

As part of this study, 'expected' nutrient balances were developed for forest, pasture, and urban land use categories to help guide the model application and calibration effort for those land segments for which the new HSPF Version 11.0 AGCHEM module was applied to simulate the detailed nitrogen dynamics. Consequently, the AGCHEM sections replaced the PQUAL sections in the Watershed Model for forest for only the N species, and for pasture for both N and P species. Although the preliminary nutrient balances for the urban land use were developed, the nutrient loadings from the urban segment in the Model were still simulated using PQUAL, as in Phase III; the basis for this decision is discussed in Chapter 3.

Tables 1 and 2 (at the end of this chapter) show the typical or expected nitrogen and phosphorus balances, respectively, for different major crops and land cover/use categories. The information in the tables is presented in a 'production' sense by estimating the annual INPUTS and OUTPUTS for the soil-plant system. The INPUTS represent external additions to the system, such as nutrient applications (i.e. fertilizer and manure), in addition to net mineralization from the soil that supplies plant-available inorganic nutrients. The OUTPUTS represent various loss mechanisms, plus plant uptake (e.g. through harvest or plant retention) that extracts the nutrients from the soil impacting the potential for nutrient export and losses. Thus, although mineralization and plant uptake are not truly external to the soil-plant system, they are most often key components in establishing representative nutrient balances for most land use/cover categories.

A review of the literature was performed to develop the nutrient balances for each category. The nitrogen balance for forest was derived primarily from information in the report by Oak Ridge National Laboratory (ORNL; Hunsaker et al., 1994) that was the basis for the algorithm enhancements to AGCHEM for the forest N cycling (Bicknell et al., 1996). Since HSPF does not currently have the capability to simulate the forest P cycling in detail, the PQUAL module was used for P loading simulations and hence we did not develop the P balance for forests. Also, the nutrient balances for agricultural croplands developed during Phase II (Donigian et al., 1994) were used in this study and are included in Tables 1 and 2. In this chapter (below), we briefly discuss the development of the 'expected' nutrient balances for each land use/cover as background for the values shown in the tables.

## Forest Balances

In the previous CBP modeling efforts, the PQUAL module in HSPF was used to compute the N and P loadings from the forest segments based on user-defined potency factors and subsurface concentrations. Since the Chesapeake Bay watershed has approximately 60% forested land and there was concern regarding the level of N loadings from these areas, there was a need to simulate the N cycling in forests with a more detailed mass balance approach that would also allow more direct consideration of atmospheric deposition inputs and impacts.

The ORNL report (Hunsaker et al., 1994) provided the design details for the enhancement of the AGCHEM/NITR module in HSPF based on an extensive literature review of forest nitrogen pools and fluxes, review of monitored N data from the CBP region, and available N models. The literature review focused on the data collected from two studies: the International Biological Program which provided data on 116 forest research sites around the world, and the Integrated Forest Study that provided 17 forest research sites (16 in North America). The information and data collected at these sites and subsequently presented in the ORNL report formed a reasonable basis for developing the nitrogen balance shown in Table 1, besides serving as a tool for the development of forest N module. Based on the review of available literature and information provided in ORNL report, the following general summary is presented.

- The primary sources of input to forests are atmospheric N deposition, with nitrogen fixation for some species, along with plant available N (inorganic N) from mineralization. Forest fertilization can be important in silvicultural activities and should be included if appropriate for a specific site assessment; we have not included forest fertilization in Table 1.
- The major pathways by which N export losses occur include leaching from soil and denitrification. Also, the surface runoff losses are generally small except when the forest system has reached higher levels of N saturation (Stoddard, 1994). Although plant uptake is not a true 'loss' from the system, it is a key component in the overall balance.
- The other processes that play important roles in forest N cycling are retention of ammonium-N by soils, immobilization of available nitrogen by microorganisms, and return of plant N to the soil both belowground and through the forest litter layer. See Hunsaker et al (1994) and Bicknell et al (1996c) for additional details.
- Since mineralization and plant uptake are such dominant components of a forest N balance, an accurate accounting of their fluxes is critical to modeling the N cycling and export to waterbodies.

## Pasture Balances

A significant portion of the Chesapeake Bay region consists of pasture, or grassland ecosystems. The grassland/pasture ecosystem presents a wide diversity of environments, productivity and degree of management. The limited literature data available for the input-output dynamics of nutrients in both grasslands and pastures are often based on studies conducted across the continental U.S. and are not specific to CBP region. However, based on the review of available literature data on nitrogen cycling

in these ecosystems, the following general conclusions are presented. Since there are very little literature data available on phosphorus cycling in the grassland systems, many of the corresponding components were assumed to be analogous to N cycle components.

- The principal sources of N inputs are atmospheric deposition, manure and N fertilizer applications, along with the mineralization contribution to plant-available N as noted above for forests. Symbiotic and nonsymbiotic fixation of  $N_2$  is considered small or insignificant under typical grassland conditions (Woodmansee, 1978).
- The N uptake by plants (aboveground, belowground and understory) are in the range of 65-80% of the total N input (Legg and Meisinger, 1982; Muchovej and Rechcigl, 1994). Hence, an average 73% plant N uptake was assumed in Table 1.
- In pasture, loss due to volatilization is significant (Muchovej and Rechcigl, 1994). About 10-25% is lost due to volatilization of  $NH_3$  from animal urine and feces while about 5% is lost due to surface runoff (Meisinger and Randall, 1991; Legg and Meisinger, 1982). Consequently, an average 17% volatilization loss and 5% surface runoff loss were assumed in Table 1; clearly, these values will vary by site-specific conditions.
- Denitrification is not a significant factor in N balance for most pasture and grasslands (Woodmansee, 1978). This is probably due to the fact that native and extensively managed grasslands are N deficient (Muchovej and Rechcigl, 1994). However, denitrification is very site-specific and was assumed to be similar to hay land for our balance.
- Some studies indicate that leaching is an important factor while other studies indicate leaching is either small or insignificant in these systems (Woodmansee, 1978; Legg and Meisinger, 1982; Keeney, 1982). Since very little research has been done on nitrate leaching from grasslands in the U.S. (Muchovej and Rechcigl, 1994) and those studies were conducted at different soils, climatic conditions and vegetation type, it is difficult to generalize the leaching potential of pasture land. However, subsurface losses are one of the major pathways by which N is transported from grasslands (Muchovej and Rechcigl, 1994). Hence, the leaching and subsurface losses were assumed to be the same as that for hay lands since hay and pasture lands have similar conditions.
- Mineralization and immobilization are important factors in the grassland N balance. However, data are not available on the mineralization and immobilization rates for grassland systems. As mentioned above, since pasture and hay lands have similar conditions, mineralization and immobilization for pasture were assumed to be in the same range as that for hay lands. For conditions where manure inputs are significant, mineralization rates in the surface soil layers should reflect the higher values common to the readily mineralizable portion of manure organics.

## Urban Balances

There are very few studies and literature data on the nutrient dynamics in an urban environment. Although the few available studies were performed in parts of the northeastern U.S., they provide

current state of knowledge on the fate of the fertilizers applied to home lawns. Based on the review of available literature data, the following general conclusions are presented. Since there are no literature data available on phosphorus cycling in urban land use, it was assumed to be analogous to N cycling in our tables.

- The principal source of N input is fertilizer N applied to lawns. Intensively managed turfgrass receives between 100-200 lb N/ac/yr (Muchovej and Rechcigl, 1994; Petrovic, 1990; Morton et al. 1988; Gold et al., 1990).
- In general, the N uptake by turfgrass is in the range of 5-74% of the total N input depending on the N release rate, application rate, and species of grass (Petrovic, 1990). On an average, about 35-60% of the applied N is found in clippings while about 14-21% of the fertilizer N is found in a thatch layer (Petrovic, 1990; Muchovej and Rechcigl, 1994). Therefore, the total N taken up by turfgrass is in the range of 50-80%. In Table 1, we assumed that an average 65% of the total N input was taken up by plants.
- Loss of applied fertilizer to the atmosphere as either ammonia due to volatilization or as one of several nitrous oxide compounds (e.g. denitrification) is a significant factor in the N balance of turfgrass (Petrovic, 1990). Factors such as presence or absence of thatch, irrigation and humidity can affect the rate of volatilization. The soil moisture and temperature have a significant influence on denitrification rates. About 10-36% of the applied fertilizer N is lost due to volatilization and/or denitrification (Petrovic, 1990). In Table 1, we assumed that an average 23% was lost due to volatilization and denitrification.
- The fertilizer management practices, soil texture, and irrigation appear to have influence on the leaching losses in turfgrass. Even though the leaching losses from turfgrasses are variable, in general these losses are less than 10% of the applied N (Muchovej and Rechcigl, 1994; Morton et al. 1988). Hence, we assumed that ten percent of the total N input is lost due to leaching.
- Surface runoff losses are minimal (less than 7% of the total waterborne loss) in turfgrass with permeable soils (Morton et al. 1988; Petrovic, 1990). For our purposes, we assumed that about 5% of the total N input is lost in surface runoff.
- Mineralization rates are not known or little research has been done for turfgrass (Petrovic, 1990). However, we assumed that N and P mineralization rates for urban lawns are in the same range as that for hay and pasture land. Studies comparing rural and urban forest N cycling indicate lower mineralization rates, less cycling, and lower labile N and nitrification in the urban environments possibly due to pollution effects on vegetation and litter quality (Goldman et al., 1995; White and McDonnell, 1988).

A significant limitation in applying the urban nutrient balance within the framework of the Watershed Model is the lumped, or aggregate, nature of the urban land use segment that includes residential, commercial, industrial, parks, etc. A more refined definition of the urban category, with the specific activities and land cover is needed to attempt a nutrient balance modeling approach (see Chapter 3).

## **Agricultural Cropland Balances**

The nitrogen and phosphorus balances developed for croplands during the Phase II modeling effort (Donigian et al., 1994) were also used in this study without modification. The values included in Tables 1 and 2 are typical nitrogen and phosphorus balances expected for Corn, Soybean, Grains and Hay when the nutrients are applied at agronomic rates meeting crop requirements. Moreover, since plant uptake amounts are a function of crop yields, the uptake values are based on average yields expected for the Chesapeake Bay region. Our experience with using these values for agricultural croplands indicates that wide variations can be expected depending on site-specific conditions. For example, yields can vary with species, double-cropping and winter cover crops will increase uptake levels, and the composition of nutrient inputs (e.g. organic versus inorganic), especially for manure and sludge applications, will have a major impact on the N and P balance components. Thus, users should attempt to develop site-specific balances to the extent possible and/or refine the values in the tables for specific local conditions.

## **Closure**

The nutrient balances in Tables 1 and 2 for forest, pasture and urban land uses were based on literature data collected in different parts of the U.S., but with a specific focus on the Chesapeake Bay region, while the values for the croplands are more directly pertinent to the Bay region.. Even though the data may have been derived from somewhat diverse sites and conditions, and the techniques used in collecting the data may have been different, the available literature and the data formed a reasonably good basis for determining the general magnitude of many of the nutrient balance components. Model users should use these balances as general guides in evaluating simulation results with the knowledge that local conditions can have a major impact on the values shown in the tables. As noted above, these balances should be updated and/or modified whenever more site-specific data are available.

**Table 1. Typical Nitrogen Balance For Major Crops and Land Use/Land Cover Categories (lb/ac/yr)**

	Corn <sup>†</sup>	Soybeans <sup>†</sup>	Grains <sup>†</sup>	Hay <sup>†</sup>	Forest <sup>†</sup>	Pasture	Urban
<b>INPUTS:</b>							
Fertilizer/Manure	100-160	25-35	50-100	30-60	0	10-60 <sup>†</sup>	100-200 <sup>†</sup>
Atmos. Deposition	7-10	7-10	7-10	7-10	7-10	7-10	7-10
Mineralization	25-40	25-40	25-40	25-40	40-140	25-40 <sup>††</sup>	25-40 <sup>††</sup>
Totals	132-210	57-85	82-150	62-110	47-150	42-110	132-250
<b>OUTPUTS:</b>							
Plant Uptake	120-150	25-40 <sup>2</sup>	60-90	30-55	50-150	31-80 <sup>3</sup>	86-163 <sup>7</sup>
Surface Runoff	2-5	1-3	2-4	1-3	1-2	1-5 <sup>4</sup>	5-10 <sup>8</sup>
Leaching & Subsurface Runoff	10-25	10-15	5-15	5-15	1-5	5-15 <sup>††</sup>	13-25 <sup>9</sup>
Volatilization & Denitrification	15-25	5-15	10-20	10-20	1-10	7-19 <sup>5</sup>	30-58 <sup>10</sup>
Totals	147-205	41-73	77-129	46-91	53-167	44-119	134-256
Δ STORAGE	-15 to +5	+16 to +12	+5 to +21	+16 to +10	-6 to -17	-2 to -9	-2 to -6

**Note:**

- <sup>†</sup> - From Chesapeake Bay Program Phase II report (Donigian et al., 1994)
- <sup>††</sup> - Approximately 60% of the Segments in CBP region receives 10-20 lb/ac while about 20% receives greater than 20 lb/ac and the rest receives less than 5 lb/ac (Source: M. Palace, CBPO, personal communication, 1996)
- <sup>1</sup> - Since no literature data is available it is assumed to be in the same range as that for hay
- <sup>2</sup> - ORNL Report (Hunsaker et al., 1994)
- <sup>3</sup> - Represents uptake from the soil, approximately 25% of total uptake, with 75% supplied by fixation (Tisdale et al., 1985)
- <sup>4</sup> - 73% uptake - average of 65-80% (Legg and Meisinger, 1982, Muchovej and Rechcigl, 1994)
- <sup>5</sup> - 5% loss in surface runoff (Legg and Meisinger, 1982)
- <sup>6</sup> - 17% volatilization - average of 10-25% (Meisinger and Randall, 1991); Denitrification is assumed to be insignificant (Woodmansee, 1978, Muchovej and Rechcigl, 1994).
- <sup>7</sup> - Literature reported range for home lawns and turfgrass (Muchovej and Rechcigl, 1994; Petrovic, 1990; Morton et al. 1988).
- <sup>8</sup> - 65 % uptake - average of 50-80% (Petrovic, 1990, Muchovej and Rechcigl, 1994).
- <sup>9</sup> - 5% of total N input (Morton et al. 1988; Petrovic, 1990).
- <sup>10</sup> - 10% of total N input (Muchovej and Rechcigl, 1994; Morton et al. 1988).
- <sup>11</sup> - 23% of total N input (average of 10-36%) (Petrovic, 1990)

Table 2. Typical Phosphorus Balances For Major Crops and Land Use/Land Cover Categories (lb/ac/yr)

	Corn <sup>+</sup>	Soybeans <sup>+</sup>	Grains <sup>+</sup>	Hay <sup>+</sup>	Forest <sup>+</sup>	Pasture	Urban
<b>INPUTS:</b>							
Fertilizer/Manure	20-40	10-30	10-30	10-30	--	5-30 <sup>1</sup>	10-30 <sup>2</sup>
Atmos. Deposition	0-1	0-1	0-1	0-1	--	0-1	0-1
Mineralization	2-5	2-5	2-5	2-5	--	2-5 <sup>2</sup>	2-5 <sup>2</sup>
Totals	22-46	12-36	12-36	12-36	--	7-37	12-36
<b>OUTPUTS:</b>							
Plant Uptake	20-30	12-20	12-22	12-25	--	5-20 <sup>3</sup>	8-15 <sup>5</sup>
Surface Runoff	1-2	0-1	0-1	0-1	--	0-2 <sup>4</sup>	0-2 <sup>8</sup>
Leaching & Subsurface Runoff	0-1	0-1	0-1	0-1	--	0-1 <sup>2</sup>	0-1
Totals	21-33	12-22	12-24	12-27	--	5-23	8-18
<b>Δ STORAGE</b>	+1 to +13	0 to +14	0 to +12	0 to +9	--	+2 to +14	+4 to +18

Notes:

- <sup>+</sup> - From Chesapeake Bay Program Phase II report (Donigian et al., 1994)
- <sup>1</sup> - From M. Palace, CBPO, personal communication, 1996
- <sup>2</sup> - Assumed to be the same as that for hay since no literature data is available
- <sup>3</sup> - 65% uptake - average of 65-80% (assumed to be analogous to N balance, but lower values)
- <sup>4</sup> - 4% loss in surface runoff (assumed to be analogous to N balance, but more in surface)
- <sup>5</sup> - 50 % uptake - average of 50-80% (assumed to be analogous to N balance, but lower values)
- <sup>6</sup> - 2% loss in surface runoff (assumed to be analogous to N balance, but more in surface)

# **3 Application of Nutrient Balances and Model Refinements to the Shenandoah River Watershed**

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## **Overview of Model Refinements**

The model testing and refinement focussed on the evaluation of the new forest simulation procedures and AGCHEM application to the non-cropland segments, but also included other enhancements to the modeling that were included as part of the refinements under Phase IV of the CBP Watershed Model effort. The Phase III model refinement effort, discussed and reported by Donigian et al (1995) for three selected test basins, included the following changes from the earlier Phase II work (Donigian et al, 1994):

- a. Land use was updated by CBPO to 1990 conditions (Neumiller et al. 1994).
- b. Selected model segments were re-defined for finer spatial detail.
- c. Precipitation and meteorologic data was reviewed and extended through 1991.
- d. Point sources, diversion, and atmospheric deposition files were extended through 1991.
- e. The yield-based plant uptake function was used in AGCHEM.
- f. Enhanced SPECIAL ACTIONS capabilities were used to reduce the length of the model input and improve representation of chemical application practices.
- g. Atmospheric deposition was included as timeseries directly input to chemical storages for the AGCHEM segments, taking advantage of additional HSPF Version No. 11 capabilities.
- h. Benthic oxygen demand and benthic algae processes were activated within HSPF in order to improve the low DO and inorganic nutrient simulation.

As part of this study, in coordination with the Phase IV efforts of the CBPO staff, the following additional changes and model refinements were implemented:

- a. Forest nitrogen simulation capabilities (implemented within AGCHEM) in HSPF Version No. 11 (Bicknell et al., 1996a) were used for the forest segment.. The forest phosphorous simulation is the same as in Phase III, i.e. the PQUAL module of HSPF is used for phosphorous loadings.
- b. AGCHEM is used for both N and P simulations for pasture, in addition to the cropland and hay segments.
- c. Atmospheric deposition was added for all segments, including urban impervious.
- d. Septic system loads of N were estimated and input as a point load for each stream reach segment, as recommended by CBPO (L. Linker, personal communication, 1996).
- e. Minor adjustments were made to the SPECIAL ACTIONS operations to improve the representation of the nutrient applications to croplands, hay, and pasture.
- f. Manure nutrient applications in Phase II/III were reviewed by CBPO based on a manure mass balance analysis; application rates were revised and values for pasture were developed (M. Palace, personal communication, 1996).
- g. Water quality calibration included a greater focus on the impact of benthic algae processes on inorganic nutrient concentrations, in addition to review and assessment of all water quality constituents.

The Watershed Model re-calibration and refinement effort for the Shenandoah segments involved:

- a. Review, calibration, and evaluation of the simulations for the new AGCHEM applications to the forest and pasture segments, and a check of the cropland simulations, based on the expected nutrient balances developed in this study
- b. Review and comparison of nonpoint source, point source, atmospheric deposition, and septic loadings from all land use categories
- c. Calibration of selected instream water quality parameters based on comparison of simulated and observed concentrations

These tasks and simulation results are discussed below under the 'Nonpoint Source and Loading Assessment' and 'Water Quality Calibration Results' sections, following a brief discussion of the 'Hydrology Simulation' results. This chapter concludes with our 'Conclusions and Recommendations' derived from the results of these efforts and our interactions with the CBPO staff in their application of the Phase IV refinements to the entire Chesapeake Bay Watershed.

## Hydrology Simulation

The hydrology simulation for this study on the Shenandoah Basin is essentially the same as was reported by Donigian et al., (1995) for the prior study, with the following exceptions:

- a. The CBPO staff reviewed the precipitation data for the entire Chesapeake Bay Watershed Model and updated selected datasets based on an analysis of spatial variation and changes with elevation for major storm events (Neumiller et al., 1994). Except for a few storm events, these adjustments did not have a major impact on the hydrology simulation.
- b. As part of the forest nitrogen enhancements to HSPF (Bicknell et al., 1996c), model testing was performed on completely forested sites resulting in a refinement of the hydrology parameters for the forest segments. These refinements only affected the distribution between surface and subsurface flow, with no significant impact on total annual flow volumes (Donigian and Chinnaswamy, 1996). The new parameters produced less surface runoff and more interflow than previously simulated, providing a better representation of the hydrologic regime for forested watersheds.
- c. In this study, we reviewed the hydrology simulation at two sites within the Shenandoah Basin: the Basin outlet at Millville, WV, and the South Fork Shenandoah River at Front Royal, VA. In addition to the Shenandoah River at Millville, which has been the calibration station for the previous modeling efforts, we output model results for the Reach 190 which corresponds to the Front Royal station. No calibration was needed, as shown by the results below, as the model parameters used for the entire Basin were appropriate for the upper model segment.

Table 3 shows the comparison of simulated and observed flow volumes for each year and for the entire simulation period for both sites within the Shenandoah Basin. Figures 2 and 3 show the daily flow simulation results, and Figures 4 and 5 show the flow duration/frequency comparisons for both sites, respectively. The Appendix also includes these results along with the daily flow comparison at an expanded scale for a clearer definition of the two curves.

The hydrology simulation results are clearly a strength of the CBP Watershed Model. The annual volumes, flow frequency, and daily timeseries comparisons all show very good agreement between simulated and observed values. As in any modeling exercise, some differences are evident in each comparison, but the overall agreement is very good and provides a sound basis for the water quality simulation which is the focus of this effort.

## Nonpoint Source and Loading Assessment

The loading assessment involved reviewing the contaminant loadings for each constituent for each source, including nonpoint sources, point sources, septic loads, and atmospheric deposition. Tables 4 and 5 are **key tools** in this assessment; Table 4 shows the unit area (per acre) loads for each land use simulated in the Watershed Model for Segments 190 and 200 within the Shenandoah Basin, while Table 5 shows the 'percent of total load' derived from each source. These tables show only the mean values for the eight-year simulation period, with the complete results provided in the Appendix; the Appendix also includes complete summaries of the AGCHEM simulations for the forest, cropland (Hi-Till, Lo-Till, Hay), and pasture segments.

**Table 3. Shenandoah River Watershed Hydrologic Calibration: Comparison of Annual Total Observed vs Simulated Flow**

**SF SHENANDOAH RIVER AT FRONT ROYAL, VA (SEGMENT 190)**

YEAR	OBSERVED FLOW (in)	SIMULATED FLOW (in)
1984	18.60	20.05
1985	16.20	17.10
1986	7.34	7.24
1987	16.10	14.73
1988	7.71	7.06
1989	15.08	16.35
1990	13.58	15.41
1991	11.67	11.63
MEAN	13.29	13.70

**SHENANDOAH RIVER AT MILLVILLE, WV (SEGMENT 200)**

YEAR	OBSERVED FLOW (in)	SIMULATED FLOW (in)
1984	17.82	18.27
1985	12.99	14.35
1986	6.92	6.88
1987	13.95	12.09
1988	7.72	6.72
1989	12.02	13.15
1990	11.58	13.78
1991	10.50	9.99
MEAN	11.69	11.90

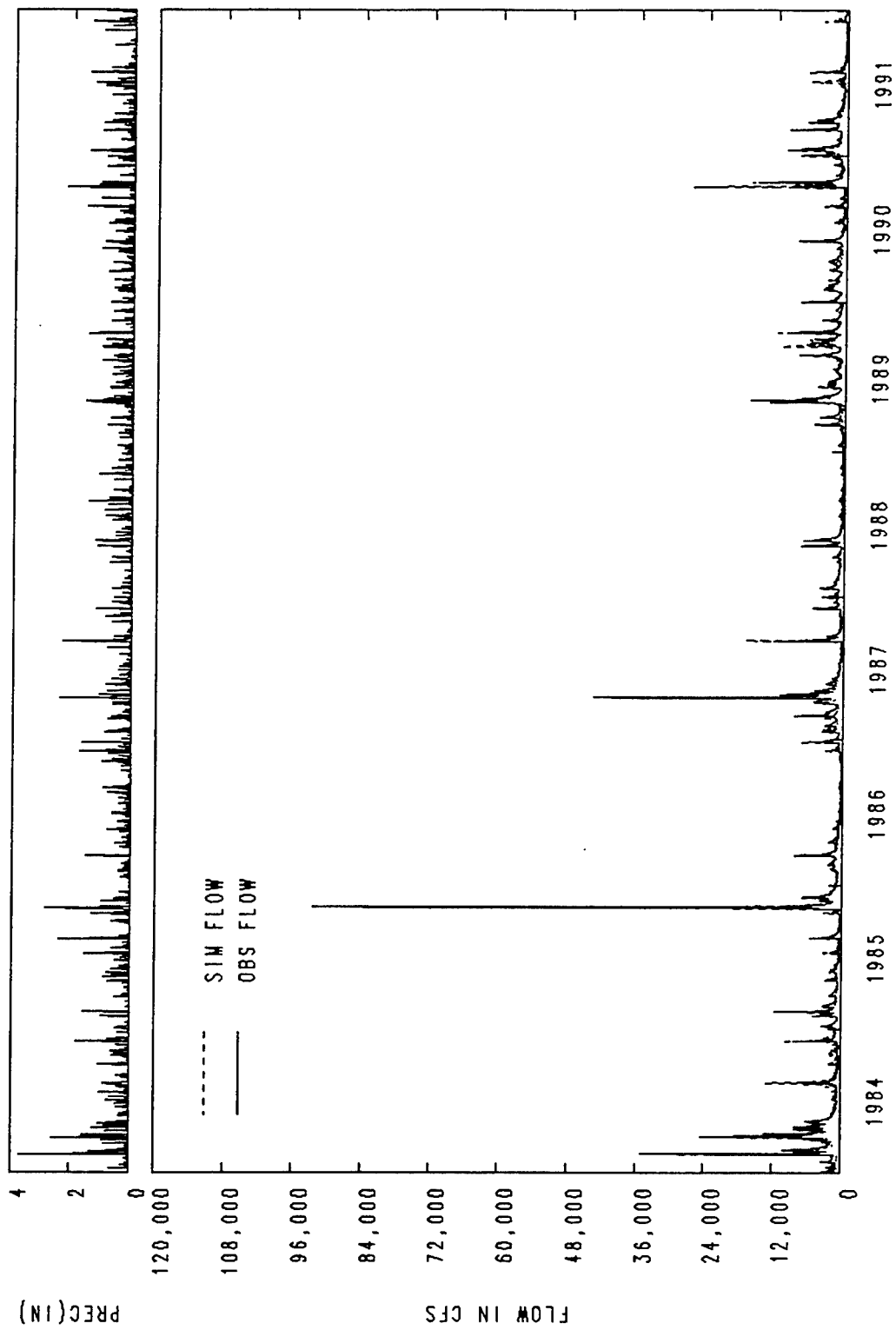


FIGURE 2. SIMULATED AND OBSERVED FLOW AT REACH 190  
SF SHENANDOAH RIVER AT FRONT ROYAL, VA

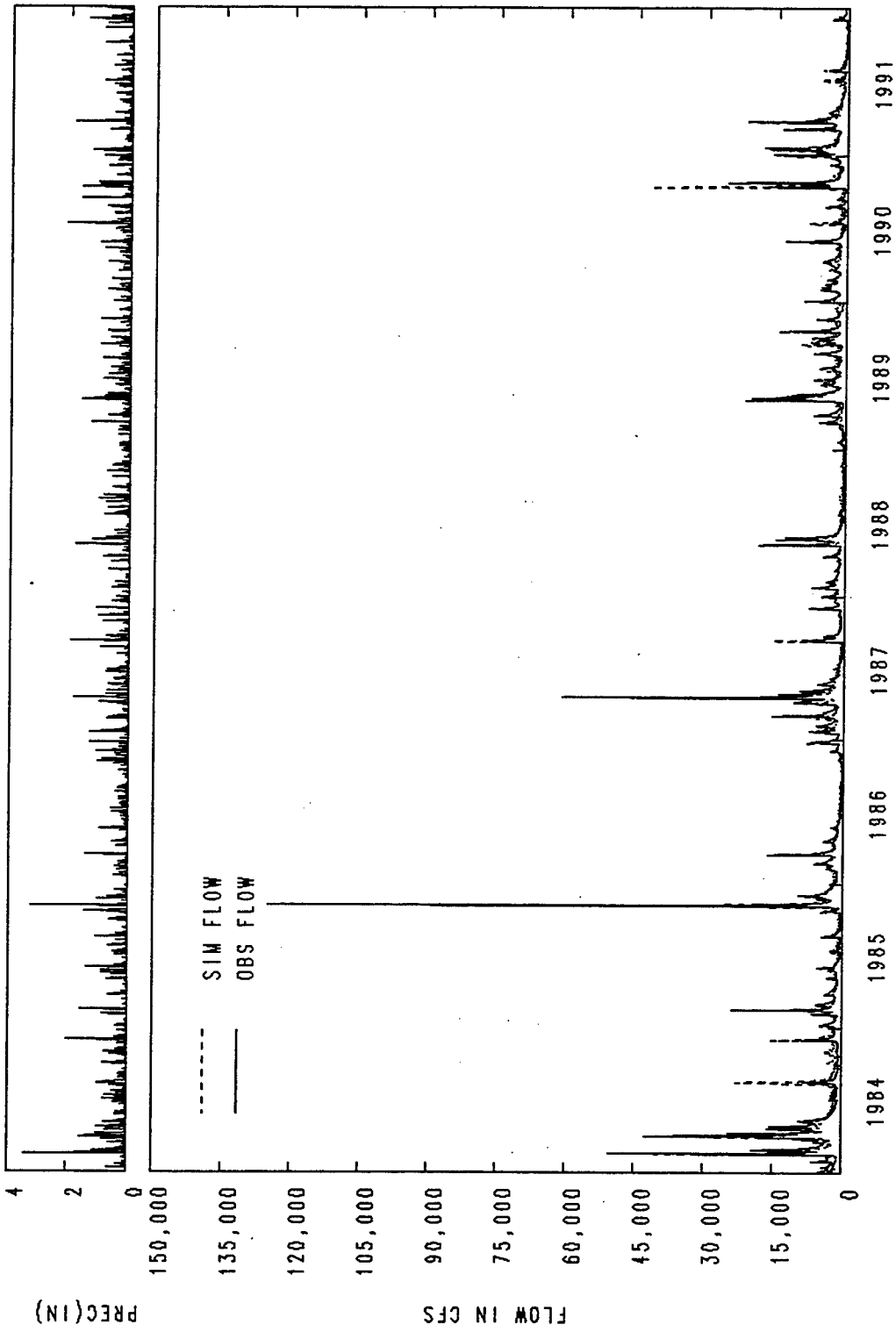


FIGURE 3. SIMULATED AND OBSERVED FLOW AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

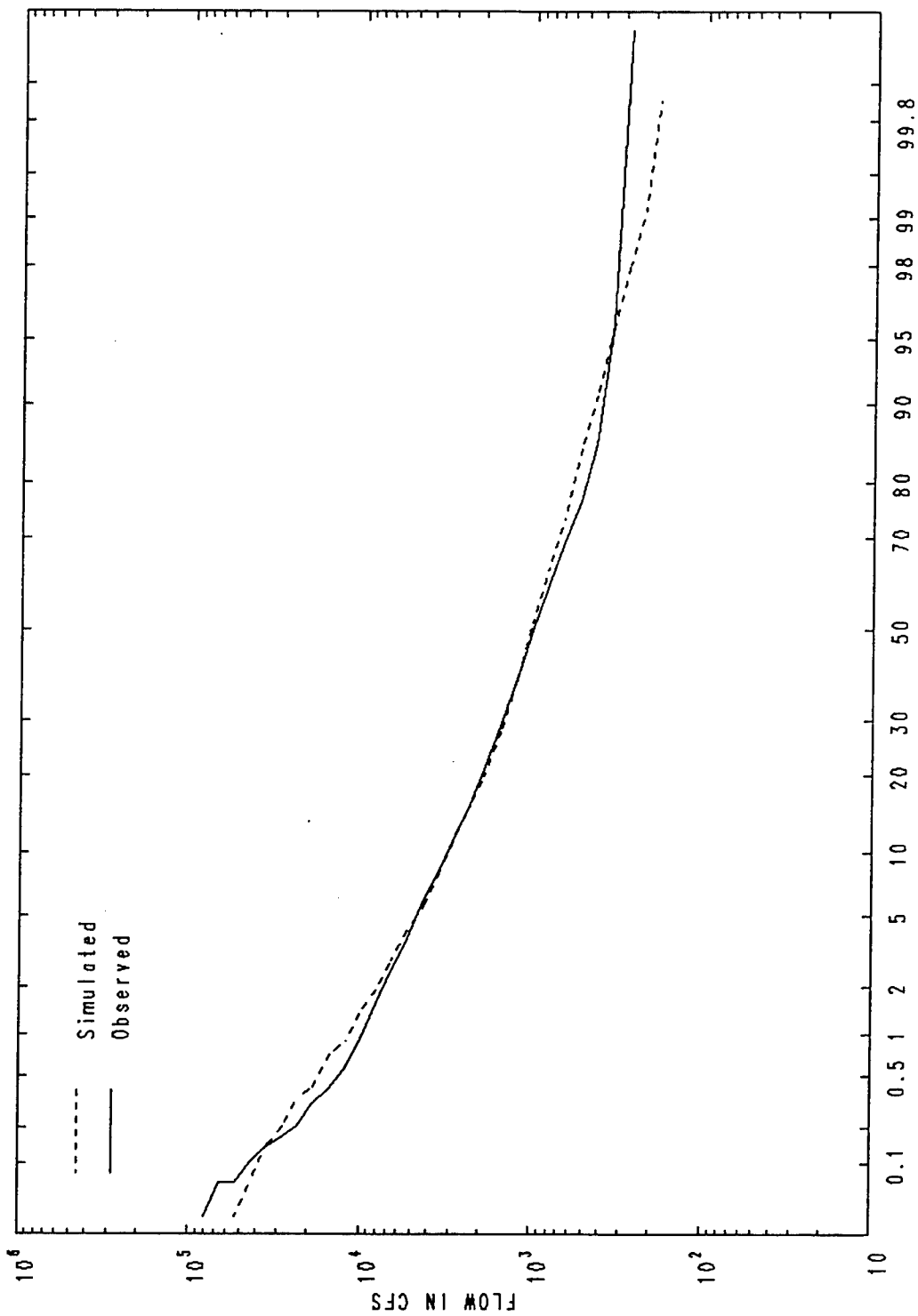


FIGURE 4. FREQUENCY ANALYSIS OF FLOW AT REACH 190  
SF SHENANDOAH RIVER AT FRONT ROYAL, VA

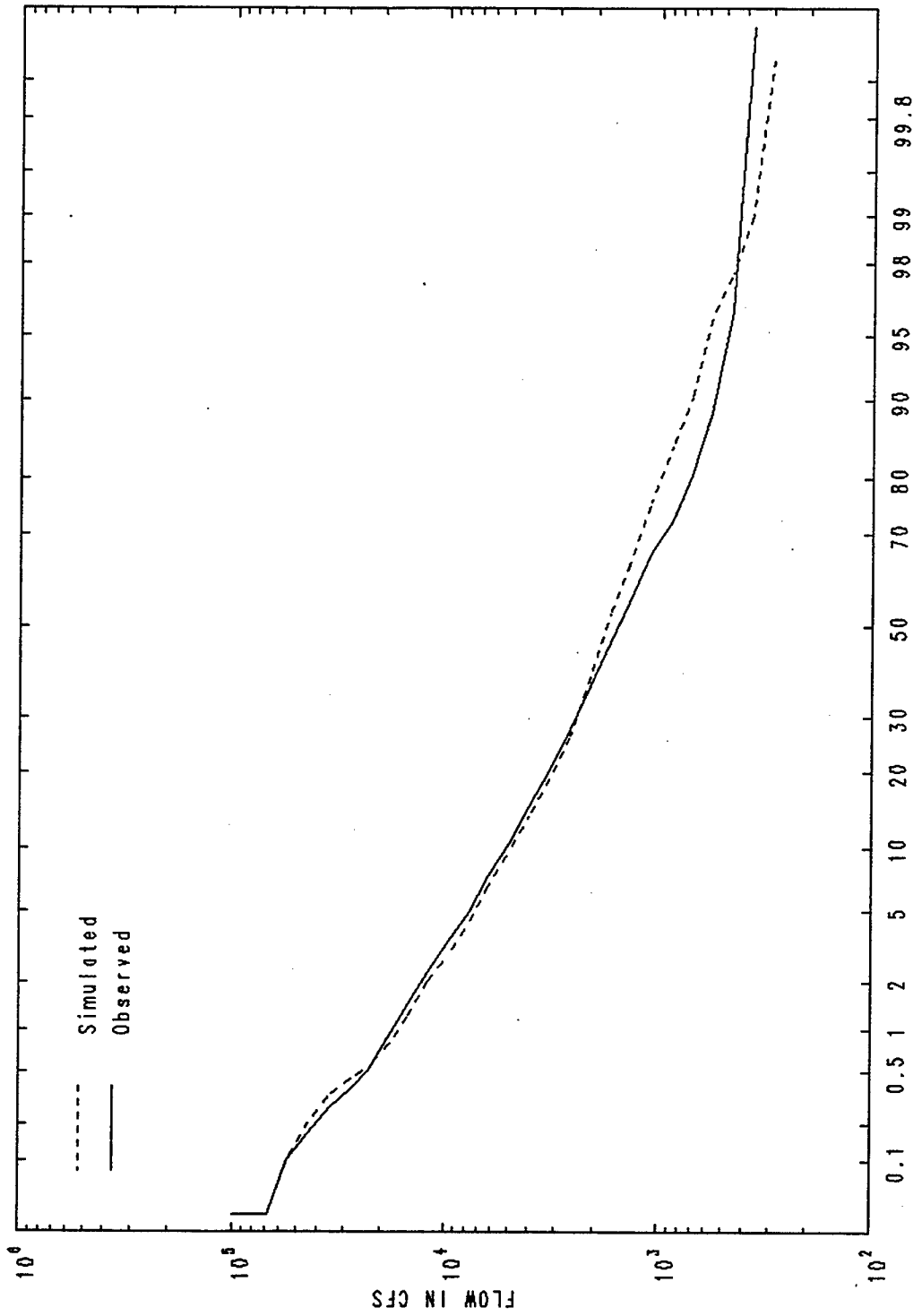


FIGURE 5. FREQUENCY ANALYSIS OF FLOW AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

Table 4 allows the model user to assess validity and reasonability of the unit area loading values by comparing them to 'expected' or generally accepted values, or ranges of values, from the literature. Table 5 allows the user to determine the relative distribution and contributions of each load source to each stream reach in the Watershed Model. Judicious and careful analysis of these two types of tables for each model segment allows the user to evaluate both the validity of the loading sources and identify those sources that may need to be re-evaluated in order to improve or refine the comparison between simulated and observed instream concentrations which are a direct result of these loads.

In this study, the nonpoint source and loading assessment involved application of a nutrient mass balance modeling approach to forest and pasture land segments, a review and relative comparison of the nonpoint loading rates for all the land uses, and an assessment of the relative load contributions from all sources as derived from the information in Table 5. These efforts involved the following components:

- a. As discussed in Chapter 2, the literature was reviewed to develop 'expected' nutrient balances for all land uses, with a primary focus on forest, pasture, and urban, as these categories had not been modeled with an AGCHEM, nutrient balance approach in prior phases of the CBP Watershed Model. The N and P balances shown in Tables 1 and 2 of Chapter 2 provided a general target for the nonpoint simulation of each land use, recognizing that significant deviations are possible due to local and regional conditions.
- b. The forest N modeling with the enhanced AGCHEM module was derived from test applications of the model enhancements to selected small forested watersheds in and near the Shenandoah Basin, and a regional-scale application as part of the code development and testing effort (Bicknell et al., 1996c). One of the key conclusions of the Phase II loading rate assessment was the identification of the relatively high loading rates of  $\text{NO}_3$  from the forest segment. In comparison with selected datasets for forested watershed sites, Hunsaker, Garten, and Mulholland (1994) noted that the  $\text{NO}_3$  loading rates used in the Watershed Model were up to ten times greater in the Susquehanna than indicated by measured data, and up to five times greater in other model segments. The model values were typically in the range of 1.0 to 6.0 lb/ac/year, whereas the measured data were in the range of 0.5 to 2.0 lb/ac/yr. Therefore in this effort we adjusted the forest AGCHEM parameters, within the overall expected N balance, to reduce the model generated forest  $\text{NO}_3$  loads to the general range of 1.0 to 2.0 lb/ac/yr.
- c. The pasture segment was converted to nutrient balance modeling, using AGCHEM for both N and P, from the empirical PQUAL approach used in earlier phases of the Watershed Model. Pasture segment parameters were initially derived from the Hay segment, with application rates and procedures for N provided by the CBPO (M. Palace, CBPO, personal communication, 1996). We developed corresponding P application rates based on the N/P ratio used in the Phase II/III manure nutrient application rates. The yield-based plant uptake option was used and calibration was performed, primarily on the N and P uptake targets, and within the general guidance of the expected nutrient balances for pasture.
- d. The data and information on nutrient balances for urban land uses is extremely limited and anecdotal. Furthermore, since our urban category is an aggregation of all relevant urban land uses within a model segment, developing an appropriate nutrient balance was problematic without a clear definition of the specific activities taking place on the urban segment.

**Table 4. Unit Area Nonpoint Source Loading Rates for Each Land Use for the Shenandoah Basin (lb/ac, except SED which is tons/ac)**

CONSTITUENT		<-----Pervious-----><-----Impervious----->						Total Load			
		FOR	HTC	LTC	PAS	URB	HAY		ANML	RES	
Segment 190	NH3	0.078	2.726	2.323	0.544	0.308	0.495	221.504	2.145	1.669	
	NO3	0.880	17.240	14.892	4.340	5.788	3.997	55.376	6.291	4.394	
	ORGN	1.020	3.324	2.842	1.303	1.972	0.683	1661.278	3.293	2.113	
	TN	1.978	23.289	20.055	6.188	8.068	5.175	1605.902	11.729	8.041	
	PO4	0.022	1.735	1.475	0.230	0.255	0.395	55.376	0.429	0.538	
	ORGP	0.025	0.927	0.762	0.245	0.282	0.186	83.064	0.470	0.263	
	TP	0.047	2.662	2.237	0.476	0.537	0.581	276.880	0.899	0.857	
	BOD	9.995	86.490	51.653	6.796	15.949	14.243	3876.315	26.625	17.403	
	SED	0.057	0.979	0.676	0.182	0.152	0.253	0.000	0.000	0.165	
Segment 200	NH3	0.057	2.007	1.632	0.353	0.212	0.317	185.347	1.949	1.244	
	NO3	1.042	13.186	11.305	3.281	4.598	3.255	46.337	5.939	3.514	
	ORGN	0.742	2.593	1.850	1.046	1.276	0.249	1390.104	3.236	1.403	
	TN	1.841	17.785	14.786	4.680	6.085	3.821	1343.767	11.124	6.071	
	PO4	0.005	1.345	1.153	0.135	0.162	0.269	46.337	0.421	0.288	
	ORGP	0.018	0.726	0.496	0.195	0.182	0.067	69.505	0.462	0.162	
	TP	0.023	2.071	1.648	0.330	0.344	0.336	231.684	0.883	0.488	
	BOD	7.265	61.286	29.006	5.558	10.320	8.100	3243.574	26.168	11.795	
		SED	0.039	0.770	0.441	0.140	0.143	0.095	0.000	0.000	0.108

**Table 5. Percent OF Total Load Contributed From Each Source in Shenandoah Basin**

CONSTITUENT	<-----Pervious-----><-----Impervious----->								Atmos Dep	Point Source	Septic Load	Total Load
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES				
Segment 190												
NH3	2.33	3.60	7.13	7.12	1.32	3.55	5.39	2.69	0.39	66.47	0.00	100.00
NO3	9.93	8.66	17.37	21.58	9.41	10.88	0.51	3.00	0.44	1.92	16.29	100.00
ORGN	23.93	3.47	6.89	13.47	6.67	3.87	31.97	3.27	0.08	6.39	0.00	100.00
TN	12.20	6.39	12.78	16.81	7.17	7.70	8.12	3.06	0.35	16.52	8.90	100.00
PO4	2.00	7.13	14.06	9.36	3.39	8.79	4.19	1.67	0.08	49.33	0.00	100.00
ORGP	4.64	7.78	14.84	20.38	7.65	8.46	12.84	3.75	0.46	19.20	0.00	100.00
TP	2.68	6.86	13.38	12.13	4.48	8.11	13.14	2.20	0.19	36.84	0.00	100.00
BOD	28.48	10.97	15.21	8.53	6.55	9.79	9.06	3.21	0.00	8.22	0.00	100.00
SED	16.98	13.10	20.98	24.06	6.56	18.31	0.00	0.00	0.00	0.00	0.00	100.00
Segment 200												
NH3	2.39	4.27	4.95	6.72	0.90	2.67	4.86	2.25	0.53	70.45	0.00	100.00
NO3	15.62	9.94	12.14	22.10	6.92	9.71	0.43	2.43	0.60	0.83	19.29	100.00
ORGN	27.83	4.89	4.97	17.64	4.81	1.86	32.32	3.32	0.14	2.19	0.00	100.00
TN	15.97	7.76	9.19	18.25	5.30	6.60	7.22	2.64	0.49	15.42	11.17	100.00
PO4	0.87	12.39	15.12	11.14	2.98	9.80	5.25	2.10	0.17	40.19	0.00	100.00
ORGP	5.83	11.86	11.54	28.49	5.95	4.36	14.00	4.11	0.87	13.01	0.00	100.00
TP	2.45	11.25	12.76	16.04	3.73	7.23	15.51	2.61	0.39	28.03	0.00	100.00
BOD	32.45	13.77	9.29	11.16	4.63	7.20	8.98	3.19	0.00	9.38	0.00	100.00
SED	18.82	18.84	15.39	30.70	6.98	9.25	0.00	0.00	0.00	0.00	0.00	100.00

Consequently, we retained the PQUAL approach used in the previous CBP Watershed Model efforts. Atmospheric deposition of N was added to the impervious urban segment, and the parameters were adjusted to avoid double-counting of the atmospheric components in the surface runoff. An analogous approach could not be implemented for the urban pervious segment because a 'potency factor' approach is used for the surface runoff loading simulation, which does not follow a nutrient balance approach (see Conclusions and Recommendations).

- e. Estimates of annual loadings of N from septic systems were developed by CBPO staff (L. Linker, personal communication, 1996), based on an assessment performed by Maizel et al. (1995) using GIS-based procedures as applied to the entire Chesapeake Bay drainage. The estimated annual loads for the Shenandoah, corresponding to 10.02 lb N/ac/yr for segment 190 and 12.83 lb N/ac/yr for segment 200, were input as NO<sub>3</sub>-N as a constant daily value for each acre of pervious urban land within each model segment.

Review and analysis of the information in Table 4, as compared to the values from the earlier study (Donigian et al., 1995) indicate the following:

- a. The forest TN and TP loadings are not significantly different, primarily because the earlier study had already reduced the forest TN loadings to the expected range of 1.0 to 2.0 lbs N/ac/year. However, the AGCHEM simulation for forests in this study does produce a somewhat different distribution, with lower NO<sub>3</sub>-N and higher Organic N loadings. The NH<sub>3</sub>-N loadings are slightly higher with the AGCHEM simulation, and the phosphorous simulation is essentially unchanged.

The BOD loads from forest have increased significantly because they are now calculated from the labile organic N loading produced by the enhanced AGCHEM module.

- b. The cropland loadings from Hi-Till, Lo-Till, and Hay have been reduced due to changes in the dates and methods of application and incorporation of nutrients through the SPECIAL ACTIONS capability. These changes helped to reduce some of the extreme NO<sub>3</sub>-N, NH<sub>3</sub>-N, and PO<sub>4</sub>-P concentration peaks from fertilizer and manure applications, and thus reduced the overall loadings of these forms.
- c. From the pasture segment, the nutrient simulation with AGCHEM and manure applications tended to increase P loads and either decrease or not change TN loads for the Shenandoah segments. For the N forms, NO<sub>3</sub>-N was reduced while both NH<sub>3</sub>-N and Organic N increased. While the relative changes for NH<sub>3</sub>-N, PO<sub>4</sub>-P, and Organic P were significant, the absolute loadings were still relatively small, in the range of 0.2 to 0.5 lb/ac/yr.
- d. Loadings from the Urban Pervious land segment did not change significantly, but the Urban Impervious segment loadings did increase due to addition of the Atmospheric Deposition inputs of all the N forms. TN loadings increased by factors in the range of 1.5 to 2.0.

The distribution of sources of each constituent shown in Table 5 is not greatly different from the distribution produced in the earlier study. Most of the numbers are either the same or have changed by at most a few percentage points, which would not have a major impact on an evaluation of the relative contributions of the different sources. However, a few numbers have changed reflecting the

loading rate changes noted above and the additional sources considered. Some of these differences are as follows:

- a. The forest segments now represent a larger relative source of  $\text{NO}_3\text{-N}$  and a smaller source of Organic N, with very little change in the TN percentage contribution.
- b. The forest segment also contributes much more BOD, due to the higher calculated loading rate, with a corresponding reduction in the contribution from other sources such as Hay, point sources, croplands, animal acres, etc.
- c. The pasture segment is now a larger contributor of P loads due to the higher loading rates with the AGCHEM simulation, resulting in a reduction in the relative contribution of the hay segment.
- d. The addition of the septic load of  $\text{NO}_3\text{-N}$  shows that it contributes almost 20% of the load in the Shenandoah. With this additional load and the reduced forest  $\text{NO}_3\text{-N}$  load, the relative contributions from other sources have decreased.

In spite of these differences, the key conclusions regarding source contributions from the earlier studies remain unchanged. Point sources remain a dominant source of the total  $\text{NH}_3\text{-N}$  load and represent almost half of the total  $\text{PO}_4\text{-P}$  load in the Shenandoah. In terms of TN and TP, point sources represent about 1/4 and 1/3, respectively, of the total loads, with the remaining 3/4 and 2/3 derived primarily from nonpoint sources and septic loads. Total agricultural contributions amount to about 50% of the TN load and 58% of the TP load in the Shenandoah, while the urban contributions represent about 10% of the TN and 6% of the TP. Although additional investigation of the loading rates is recommended (see Conclusions and Recommendations below), the results provided with the nutrient balance approach are a clear improvement from earlier studies and provide a sound basis for evaluating nutrient management alternatives.

## Water Quality Calibration Results

Following the nonpoint source and loading assessment, water quality calibration involved adjustment of selected instream parameters to improve the overall comparison between observed and simulated concentrations. As noted above, the simulation of benthic oxygen demand and benthic algae were activated in the earlier effort (Donigian et al., 1995) as part of the Phase III water quality calibration. These processes provided additional mechanisms to improve and better represent the instream simulation. The primary focus of the calibration was on maintaining reasonable levels of phytoplankton and benthic algae, since no observed data was available, and adjusting the related parameters so that the nutrients, both organic and inorganic, followed the observed variation with the revised loadings from this study. Review of the water quality parameters and the algal simulation by the CBPO indicated a few potential adjustments to the instream parameters (G. Shenk, personal communication, 1996), and refinements to the algal simulation to increase benthic algae concentrations and decrease the phytoplankton levels (L. Linker, personal communication, 1996). Through ongoing coordination with CBPO staff, these efforts provided input to our calibration work.

Figures 6 through 13 (end of this chapter) show the model results comparisons, in the form of eight-

year timeseries plots of daily simulated concentrations and the sporadic observed data, for sediment (TSS), nitrogen forms ( $\text{NO}_3$ ,  $\text{NH}_3$ , Organic N, and Total  $\text{N}_4$ ), and phosphorous forms ( $\text{PO}_4$ , Organic P, and Total P) for the Shenandoah River at Millville, WV (model segment 200). The complete results of all simulated constituents for the Millville site and for the Shenandoah River at Front Royal, VA (model segment 190) are included in the Appendix. The extent and volume of the results precludes duplication as part of this discussion, so the reader should refer to the results in the Appendix to better comprehend the results discussion below.

The water quality results from this effort are not greatly different from those produced in the earlier study, in spite of all the changes implemented, including more extensive application of AGCHEM, addition of septic loads, refinement of loading rates, and additional calibration. However, this simply indicates that the prior calibration was a good representation of the observed data, and that the changes implemented to better define the load sources were incorporated while maintaining the accuracy of the overall simulation. The real benefits of the current refinement phase of the CBP Watershed Model are realized from the extension of the nutrient balance approach to all major land use (except urban in our simulations), and the utility of this approach for nutrient management.

Below we discuss some of the areas where the current results differ from those presented earlier in Donigian et al (1995), and identify some problems that still remain for selected constituents, where further 'fine tuning' of the calibration is recommended. The specific conclusions and model results discussed by Donigian et al (1995) will not be repeated here, but they are still relevant for many of the water quality constituents whose simulation did not change significantly. Some of the key differences in the simulation results and issues identified in this work are as follows:

- a. The earlier sediment calibration was generally high with simulated concentrations higher than the sporadic observed values; thus we attempted to reduce the concentrations through limited reductions in the sediment loading rates. As shown in Figure 6, this effort was not entirely successful as the peaks are still higher than all of the observed values except for the storm of November 1985 whose flow was undersimulated. Further reductions in the loading rates does not appear to be realistic. We feel that additional improvement will require finer segmentation of the model to include shorter, more representative stream segments to better represent localized scour and deposition processes. Currently, the U.S. Geological Survey under EPA funding is developing a finer segmentation of the Potomac basin with about an order-of-magnitude increase in the number of land and stream segments (A. Lumb, personal communication, 1996). Although limited to the hydrologic and flow simulation, this more detailed Potomac model should also provide a more realistic basis for sediment and water quality simulation.
- b. The  $\text{NO}_3$ -N simulation shown in Figure 7 is acceptable but not as seasonally correct as the earlier results reported by Donigian et al (1995). We suspect that the differences primarily in late summer, fall, and winter for selected years are due mostly to the newly-added septic loads and possibly inaccuracies in the seasonal loadings from the forest and pasture segments, i.e. the added AGCHEM segments. The dotted line in Figure 7 ( and in Figure 10 for Total N) shows the simulation **without** the  $\text{NO}_3$ -N load from septic systems appears to be improved in about five of the eight years simulated. As opposed to being a constant load, the septic load should probably be 'hydrologically' driven by baseflow so that the loading to the stream will depend on the flow regime.

Both the  $\text{NO}_3\text{-N}$  and Total N simulations include occasional peaks that are well above the observed data. This is typical of most of the nutrient simulation results, and may also be due to the relatively large model segments and long stream reaches used in the Watershed Model. However, the observed data is relatively infrequent (about every two months) and one sample point exceeding 9.0 mg/l  $\text{NO}_3\text{-N}$  in the summer of 1986 indicates that much higher concentrations are possible. Adjustments in the timing and placement of nutrient applications have helped to lower some peaks, but further investigation and finer segmentation should be investigated.

- c. Both the  $\text{NH}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  simulations (Figures 8 and 11) have improved with reduced contributions from cropland (along with the reduced sediment loads), reduced peaks due to the nutrient application adjustments, and increased algal uptake due to higher benthic algae levels than in the previous efforts. Both of these constituents are highly sensitive to the algal simulation (phytoplankton and benthic algae), for which no data was available for any of the test model segments. In spite of the refinements made in this effort, algal data remains as a major data need at this time; additional instream benthic and algal data would help to assess the validity of the phytoplankton (and benthic algae) simulation and its impact on the inorganic nutrient concentrations.

While the  $\text{NH}_3\text{-N}$  peaks remain higher than most of the observations, the  $\text{PO}_4\text{-P}$  peaks are much closer than in previous efforts. However, base concentrations appear to be too low and could probably be improved with additional calibration. Both of these constituents would benefit by a finer model segmentation since they are impacted by the accuracy of the sediment simulation.

As noted earlier, for the Shenandoah the greatest fraction of the total loads for both  $\text{NH}_3$  and  $\text{PO}_4$  are derived from point sources. Thus, although the concentration peaks in Figures 8 and 11 are likely due to nonpoint sources, the point sources are major contributors to the total load.

- c. Simulation of both Organic N (Figure 9) and Organic P (Figure 12) has improved in this effort, and since Organic P is the major component of Total P (Figure 13) similar improvement is shown there. Except for the November 1985 storm, Organic N is generally well represented, although many of the peaks are still somewhat high. For Organic P, the concentrations are closer to observed than in the previous effort, but peak concentrations are also still high. The improvements result from reduced sediment loads (and associated organics), adjustments to the N/P ratios, changes to manure applications, and reductions in phytoplankton levels (which are included in the organic state variables).

With the detailed AGCHEM simulation of forests, the forest segment is now a major contributor of organic N, both labile and refractory in both dissolved and particulate forms, along with the animal acres segment. Also, for the forest segment, BOD and Organic P loads are calculated from the organic N components; thus BOD loads from forest are also a major component. As shown in Table 5, forests contribute about 25% of the Organic N load and 30% of the BOD load, while the animal acres segment contributes more than 30% of the Organic N to the stream. Both of these components need further investigation as there is little data to confirm this level of contribution.

A bed scour component for Organic N was approximated by CBPO, based on sediment scour in the upstream reach (D. Benelmouffok, personal communication, 1996), and included in their current modeling efforts, but it was not included in our model runs due to a mismatch in project schedules. Including bed scour for organics, in a manner similar to current procedures for  $\text{NH}_3$  and  $\text{PO}_4$ , is a relatively minor and straightforward code enhancement that should be implemented to allow better representation of major storm contributions of bed organics.

Although the forest simulation provides both labile and refractory organic N components (dissolved and particulate), the other AGCHEM segments (Hi-Till, Lo-Till, Hay, Pasture) are restricted to just the refractory particulate organic N and P eroded from the land surface. A more consistent approach to representing organic loadings across all land use categories is needed and should be investigated jointly with the algal simulation.

## CONCLUSIONS AND RECOMMENDATIONS

Based on the results of our investigation as presented in this study, and our interactions with CBPO staff in their ongoing Watershed Model application as part of the Phase IV effort, we submit the following primary conclusions and recommendations:

1. Finer segmentation for all stream reaches should be pursued as a major component of future Watershed Model enhancements. Increasing the spatial detail of the model by about a factor of 10x, along with appropriate detail in the precipitation and land use inputs, will help to improve all the process simulations, with specific benefits for the sediment and associated constituents, and benthic processes. Current efforts by the U.S.G.S (restricted to the hydrology and flow simulation) should provide a sound basis for increasing the segmentation detail. Similar efforts in the Patuxent River Basin (AQUA TERRA Consultants, 1994) may provide an indication of the potential water quality simulation benefits and implications of the additional segmentation detail.
2. A more consistent approach for both BOD and organics loading needs to be developed and applied consistently across all land use categories. Currently the forest simulation enhancements provide loadings of both labile and refractory organic N components (dissolved and particulate), while the other AGCHEM segments (Hi-Till, Lo-Till, Hay, Pasture) are restricted to just the refractory particulate organic N and P eroded from the land surface. The forest organic N capabilities can, and probably should, be applied to all land segments to implement this consistent loading representation. Further investigation of partitioning and transformation parameters for the organics will be needed, along with consideration of extending the forest N simulation approach to include phosphorous. In addition, as noted above, including a simple bed scour algorithm for organics is a relatively minor and straightforward code enhancement that should be implemented.
3. The current representation of septic system loads needs to be re-evaluated. The current use of a constant load has reduced the seasonality of the  $\text{NO}_3$  simulation shown in both the observed data and the previous model simulations. With the division of the urban land use category, one alternative approach would be to include a rural residential category with the baseflow

concentrations calibrated to match the annual loading rates estimated for the septic system loads. Whatever approach is selected it should allow the septic loadings to be 'hydrologically-driven' so that the seasonality of the hydrologic regime and loadings is represented.

4. The algal simulation, both phytoplankton and benthic algae, need more data, investigation, and evaluation. In this effort, the benthic algal levels were increased dramatically, by factors of 10 to 20, based on very limited data from widely scattered sites outside the Chesapeake Bay drainage. Phytoplankton levels showed an associated decrease from earlier modeling efforts due to competition for the available nutrients. It seems appropriate that benthic processes have a greater impact than represented in previous modeling efforts, but additional literature data should be identified and actual site-specific data within the Chesapeake Bay watersheds collected to confirm the general magnitude of both the benthic and phytoplankton levels represented in the model. The algal simulation has such a critical impact on inorganic nutrients levels that major improvements in their modeling will depend on establishing realistic levels for the algal populations.
5. The urban land use should be divided into separate urban categories -- residential, commercial, industrial -- each with pervious and impervious fractions, as a prelude for nutrient mass balance and AGCHEM-type model application. The CBPO has pursued an AGCHEM approach for the aggregated urban pervious segment in their current modeling efforts (L. Linker, personal communication, 1996); however, we feel this approach requires a better definition of specific urban activities in order to develop reasonable nutrient balances. With a division into separate urban categories, nutrient balances would be more representative.
6. The CBPO should explore the option of eliminating the current 'composite crop' representation in the model, developed as part of the Phase II enhancements in 1991, and move to simulating each major crop individually in each cropland category. With the widespread availability of Pentium processors running at up to 200 megahertz with gigabytes of disk storage, many of the run time restrictions that required this simplification have disappeared. Such an approach would allow more accurate representation of agricultural practices and the resulting nutrient balances.
7. In conjunction with representing each major crop, the nutrient application rates, timing, procedures, and composition distribution (both fertilizers and manure) should be closely reviewed and revised as needed. Experience with both the Watershed Model and the detailed Patuxent Model has confirmed the critical importance of the assumptions underlying the nutrient applications in the model. Issues such as double-cropping, application methods, inorganic/organic splits (e.g.  $\text{PO}_4$ /Org P splits for manure and sludge), etc. need to be investigated to improve the nutrient mass balances and simulations.
8. The forest N simulation approach should be extended to include the P cycle, so that both N and P mass balances can be implemented for all land segments. Just as the previous AGCHEM module provided a valid framework for the forest N enhancements, the P cycle processes currently in AGCHEM can be readily adapted for forested conditions. Field site testing on small forested watersheds would be needed to fully evaluate the code enhancements.

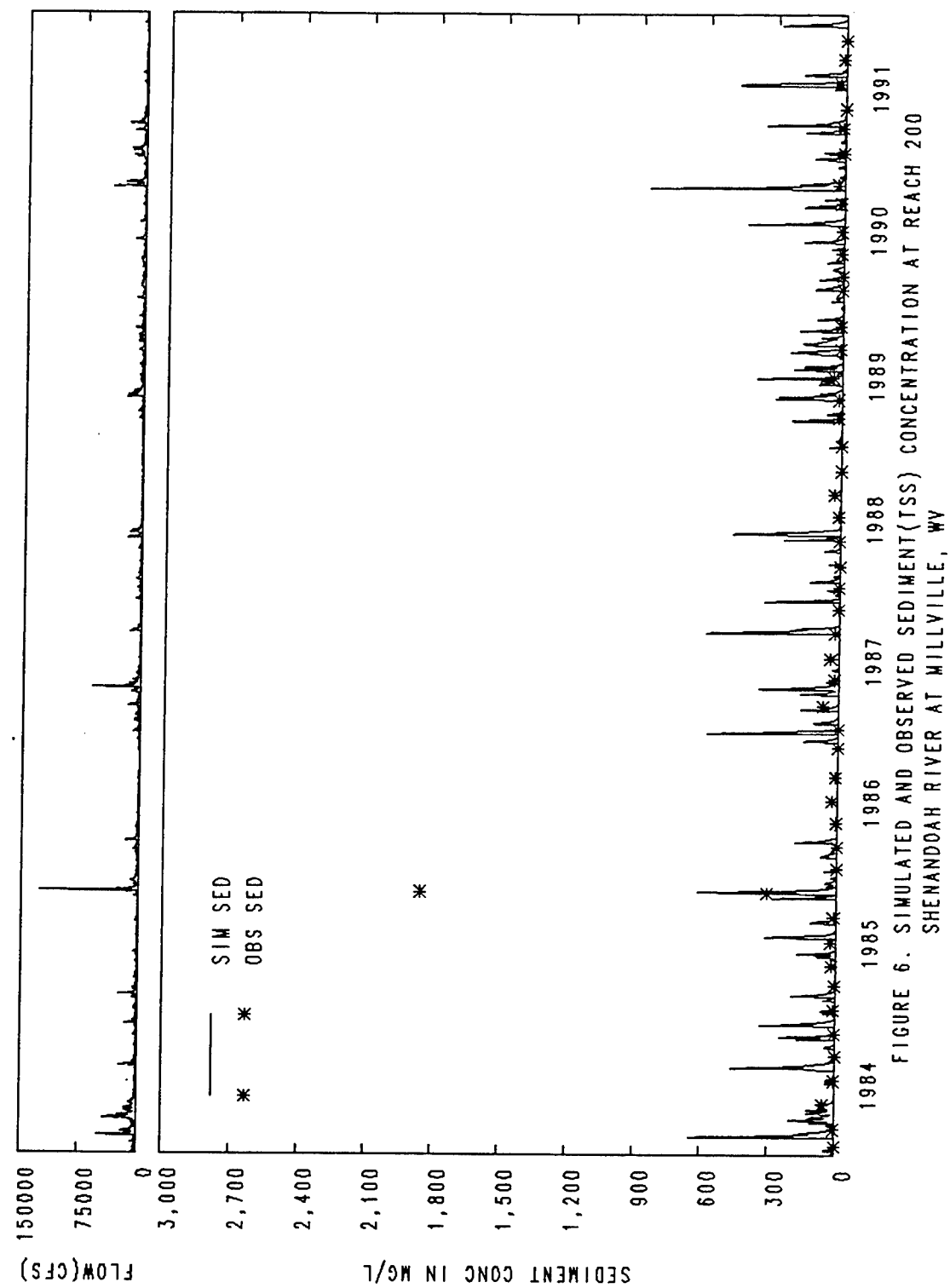


FIGURE 6. SIMULATED AND OBSERVED SEDIMENT (TSS) CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

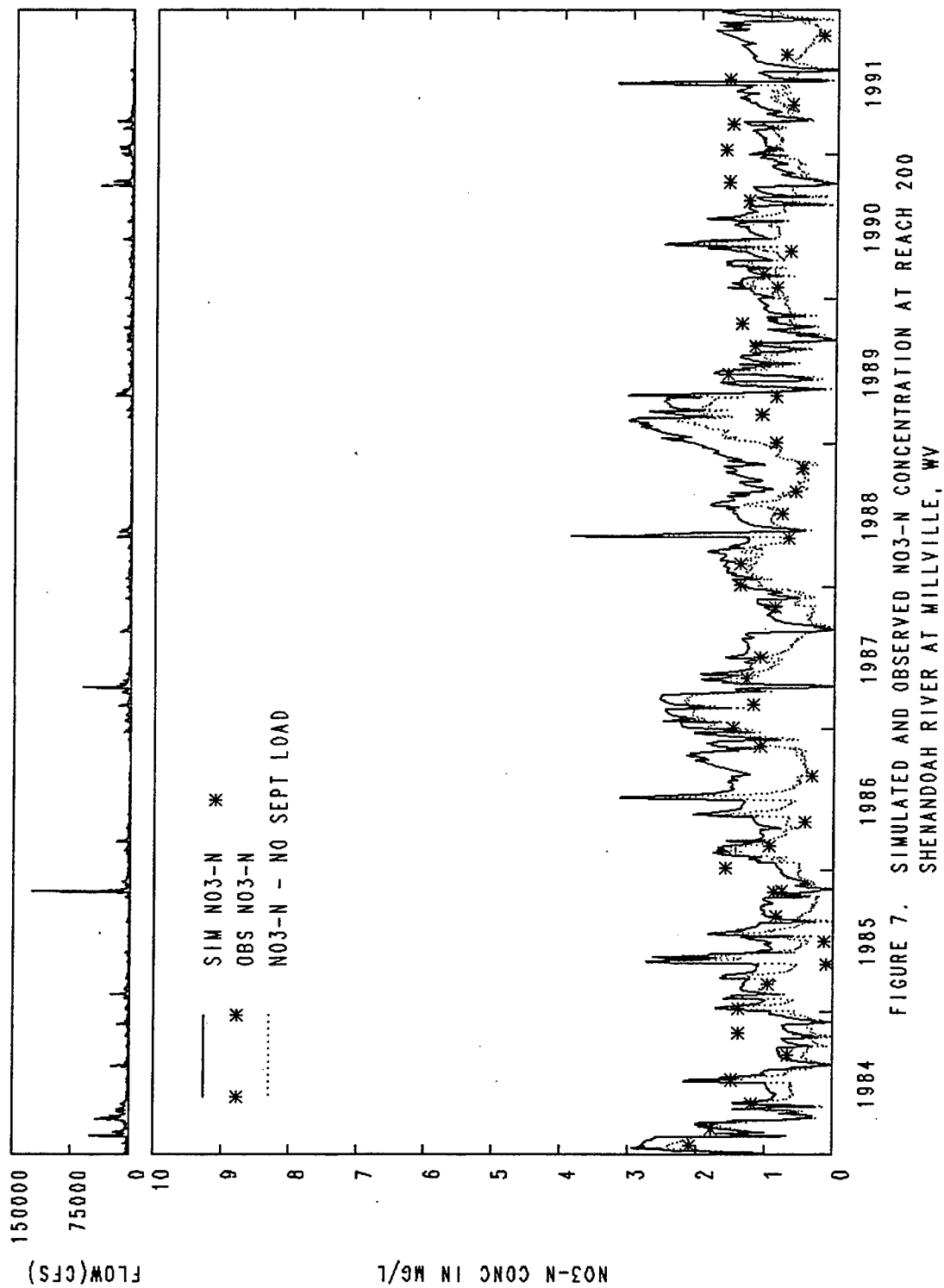


FIGURE 7. SIMULATED AND OBSERVED NO<sub>3</sub>-N CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

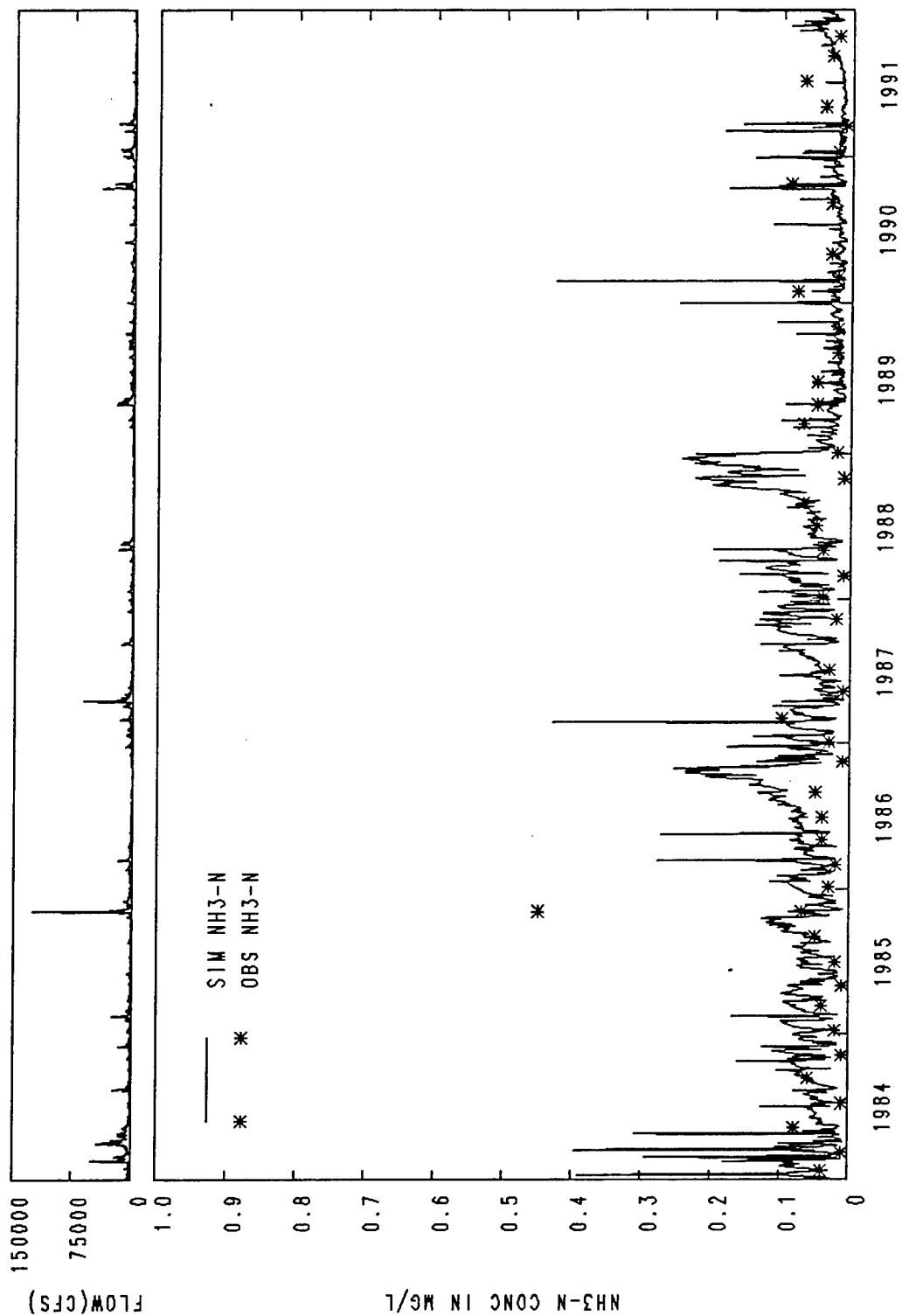


FIGURE 8. SIMULATED AND OBSERVED NH<sub>3</sub>-N CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

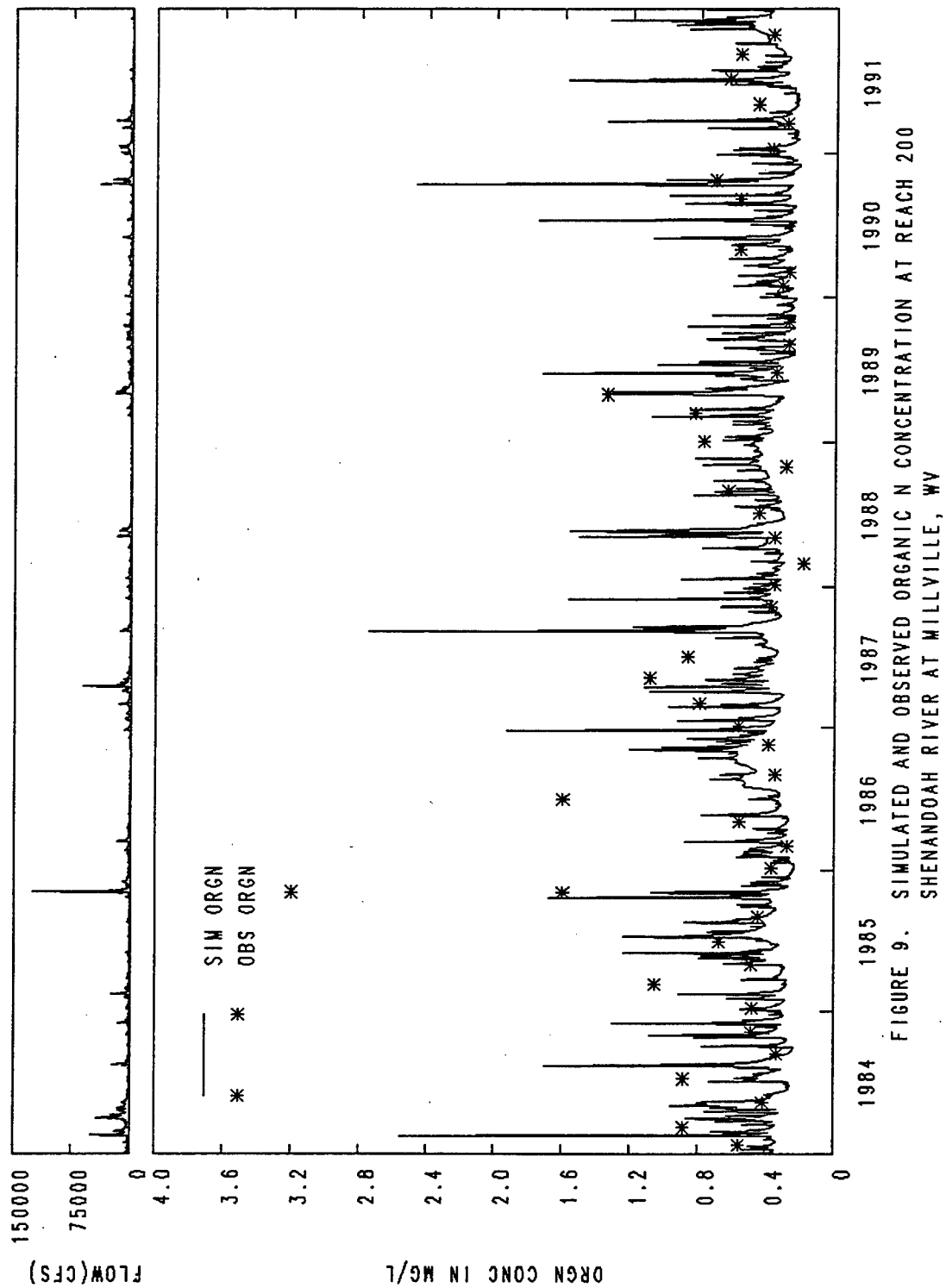


FIGURE 9. SIMULATED AND OBSERVED ORGANIC N CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

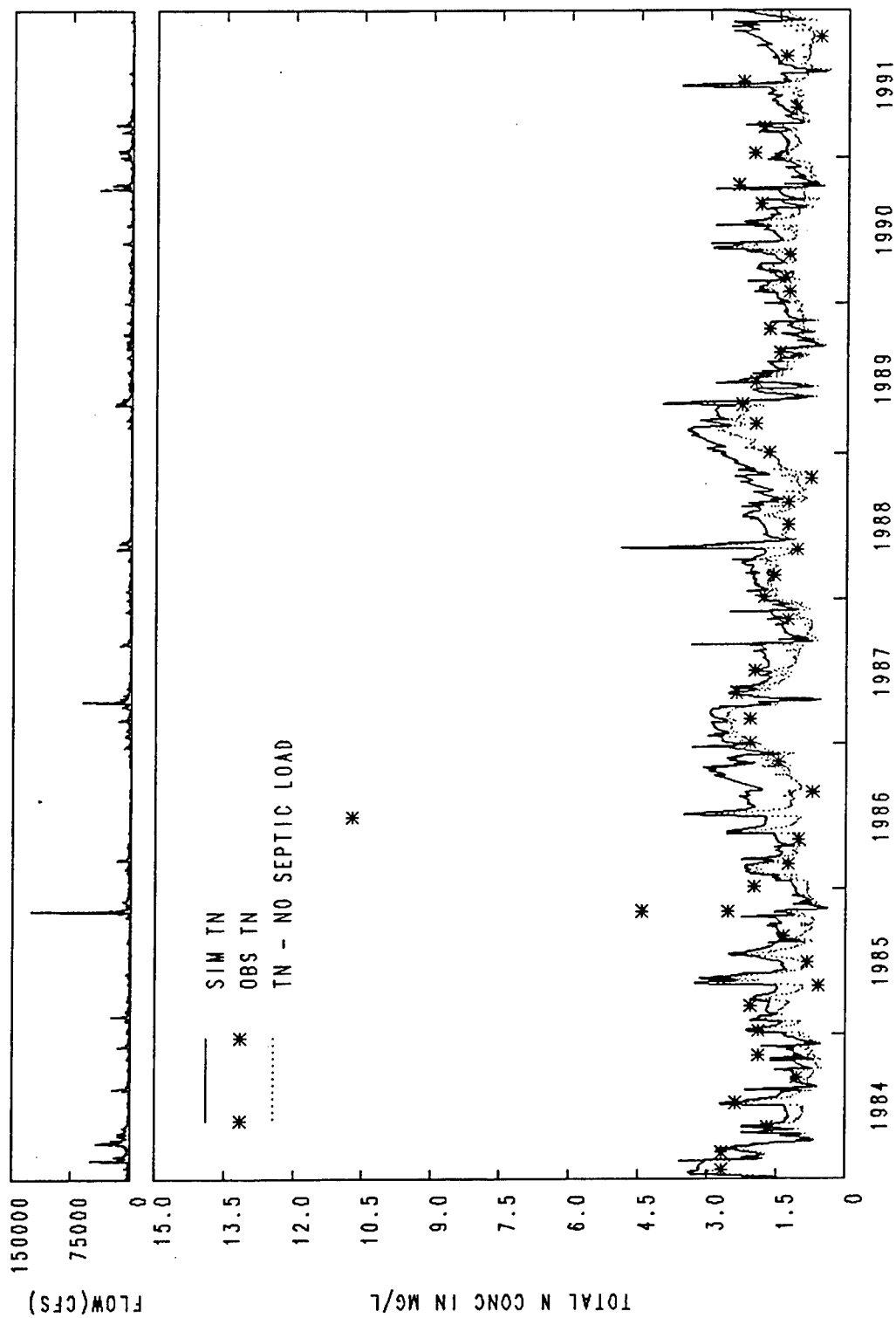


FIGURE 10. SIMULATED AND OBSERVED TOTAL N CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

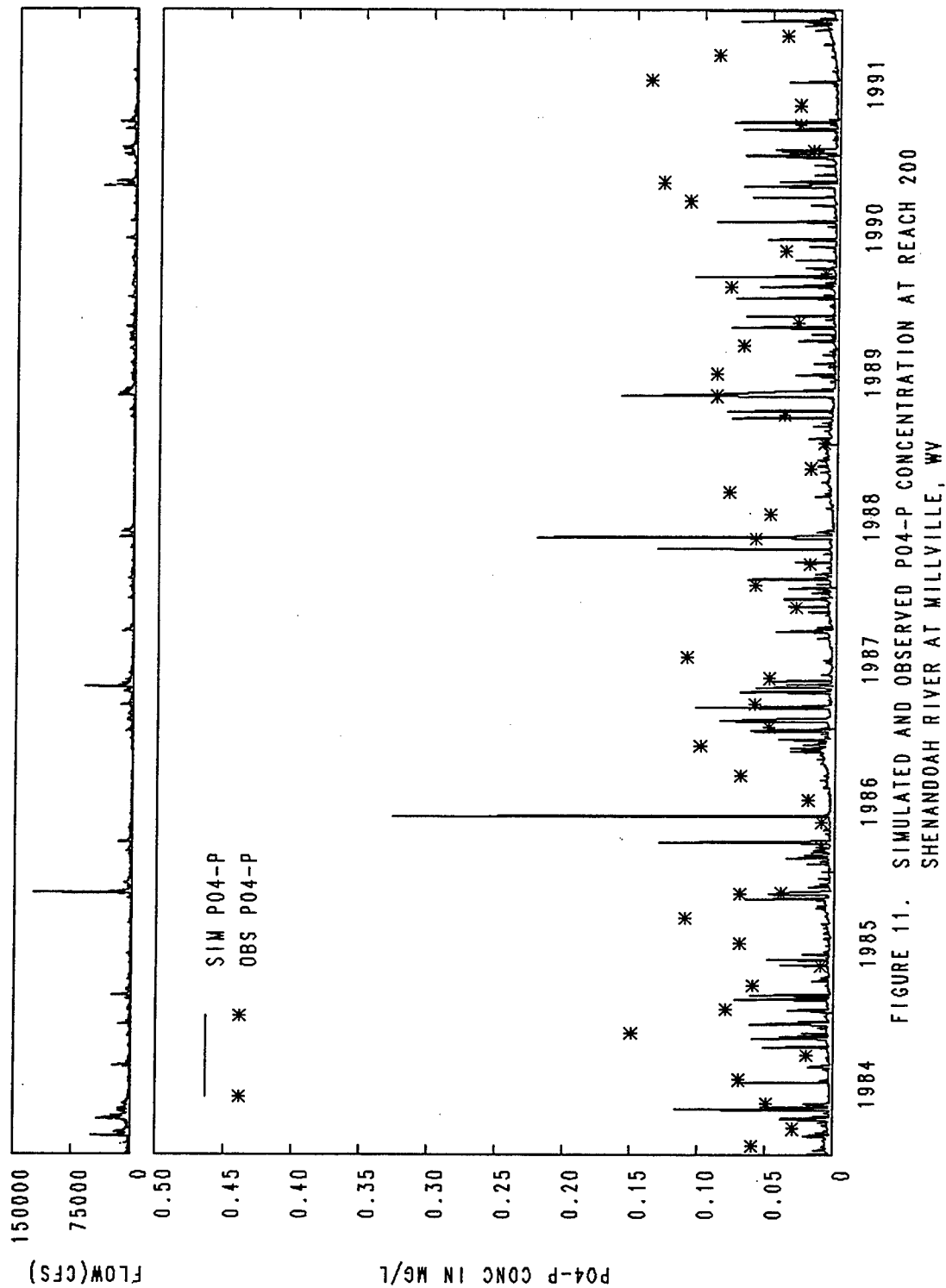


FIGURE 11. SIMULATED AND OBSERVED P04-P CONCENTRATION AT REACH 200  
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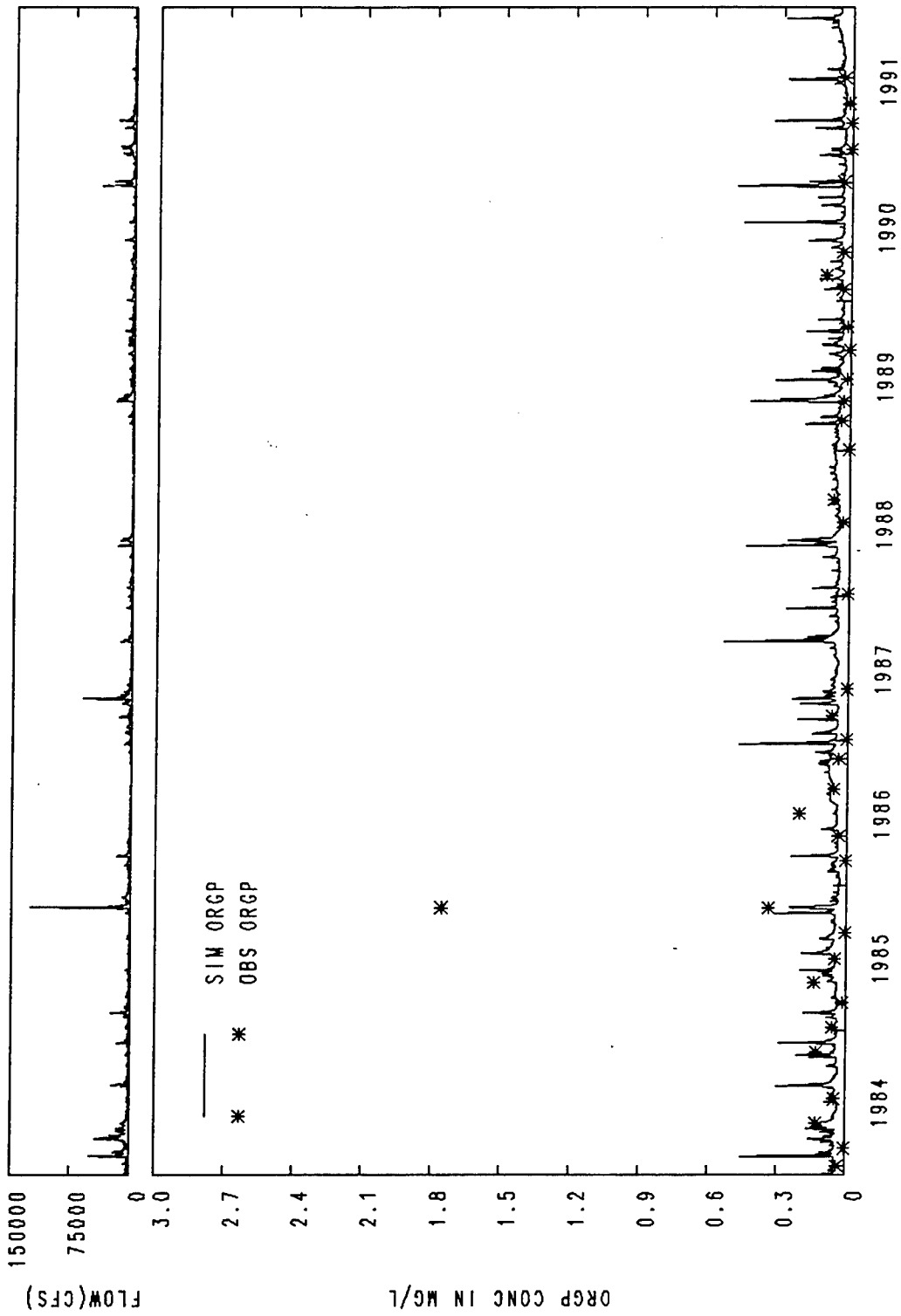


FIGURE 12. SIMULATED AND OBSERVED ORGANIC P CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

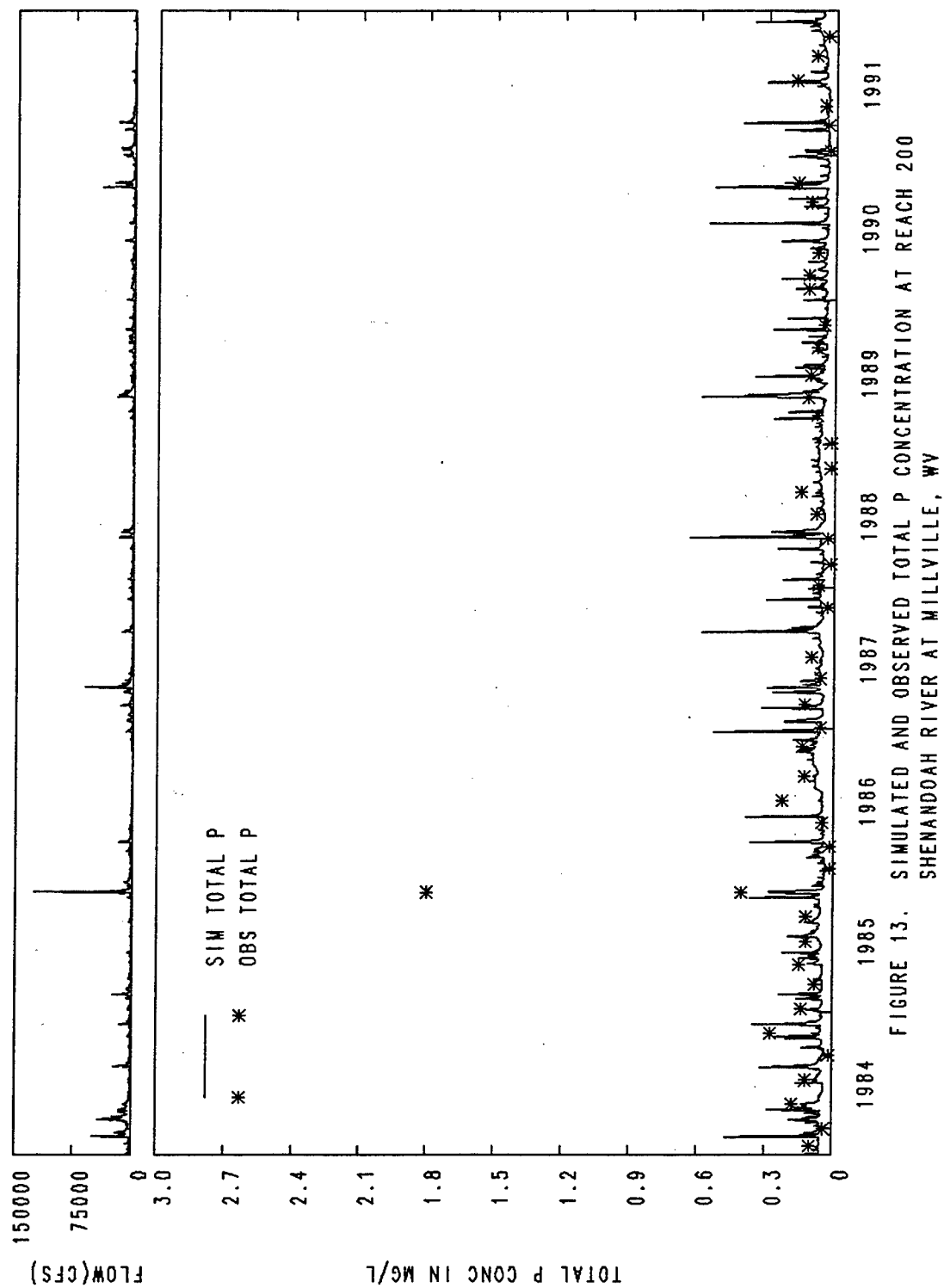


FIGURE 13. SIMULATED AND OBSERVED TOTAL P CONCENTRATION AT REACH 200  
SHENANDOAH RIVER AT MILLVILLE, WV

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# Appendix A

## Shenandoah Model Segments Results

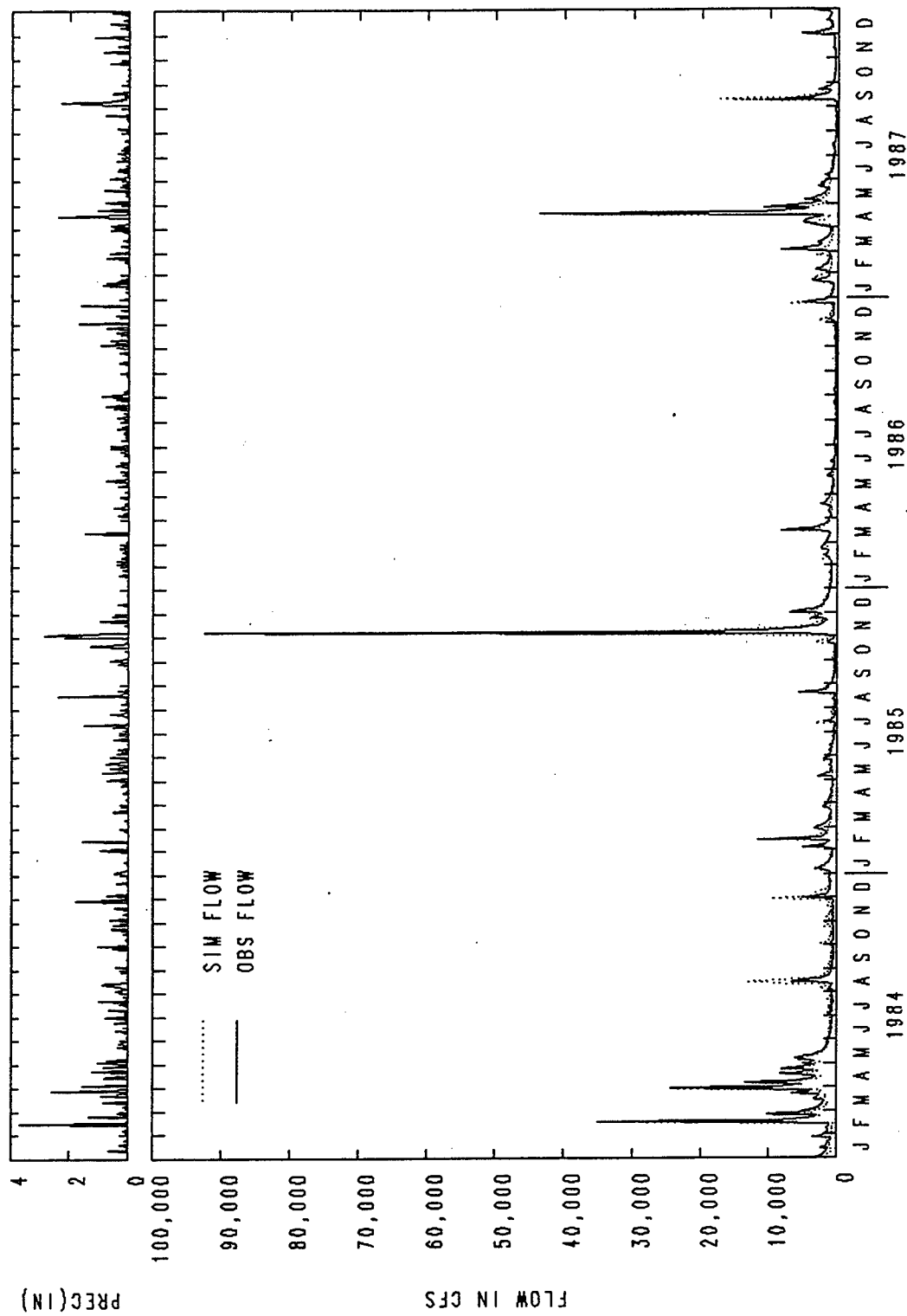
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Simulated and Observed Flow at Reach 190, 1984-87  
Simulated and Observed Flow at Reach 190, 1988-91  
Frequency Analysis of Flow at Reach 190  
Comparison of Annual Total Observed and Simulated Flow Volume  
Simulated Sediment(TSS) Concentration at Reach 190  
Simulated and Observed Water Temperature at Reach 190  
Simulated and Observed DO Concentration at Reach 190  
Simulated and Observed Nitrate-N Concentration at Reach 190  
Simulated Ammonia-N Concentration at Reach 190  
Simulated Organic-N Concentration at Reach 190  
Simulated Total-N Concentration at Reach 190  
Simulated and Observed PO<sub>4</sub>-P Concentration at Reach 190  
Simulated Organic-P Concentration at Reach 190  
Simulated Total-P Concentration at Reach 190  
Simulated TOC Concentration at Reach 190  
Simulated Chlorophyll A Concentration at Reach 190  
Simulated BOD Concentration at Reach 190  
Simulated Benthic Algae Concentration at Reach 190

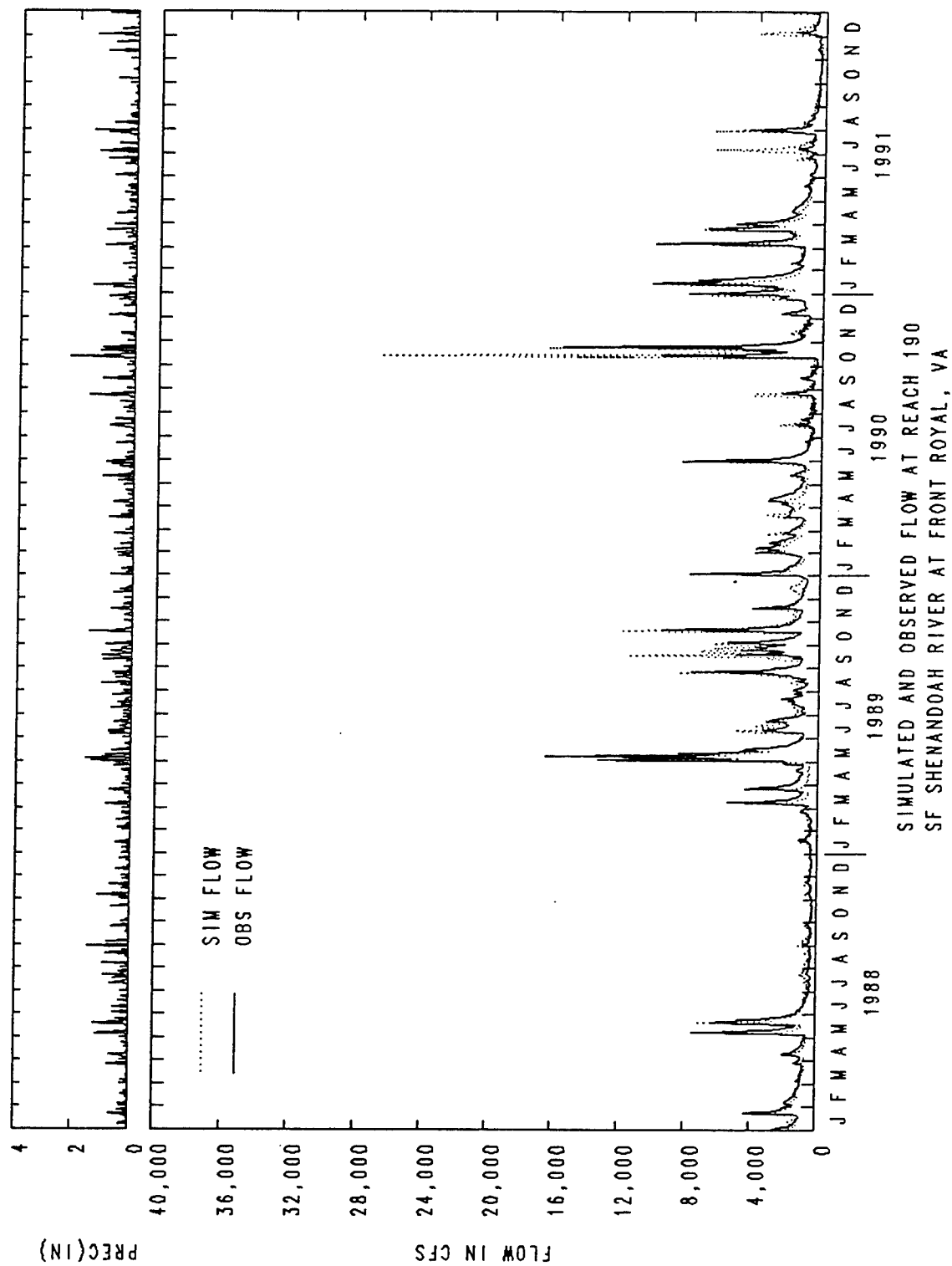
Simulated and Observed Flow at Reach 200, 1984-87  
Simulated and Observed Flow at Reach 200, 1988-91  
Frequency Analysis of Flow at Reach 200  
Simulated and Observed Sediment(TSS) Concentration at Reach 200  
Simulated and Observed Water Temperature at Reach 200  
Simulated and Observed DO Concentration at Reach 200  
Simulated and Observed Nitrate-N Concentration at Reach 200  
Simulated and Observed Ammonia-N Concentration at Reach 200  
Simulated and Observed Organic-N Concentration at Reach 200  
Simulated and Observed Total-N Concentration at Reach 200  
Simulated and Observed PO<sub>4</sub>-P Concentration at Reach 200  
Simulated and Observed Organic-P Concentration at Reach 200  
Simulated and Observed Total-P Concentration at Reach 200  
Simulated TOC Concentration at Reach 200  
Simulated Chlorophyll A Concentration at Reach 200  
Simulated BOD Concentration at Reach 200

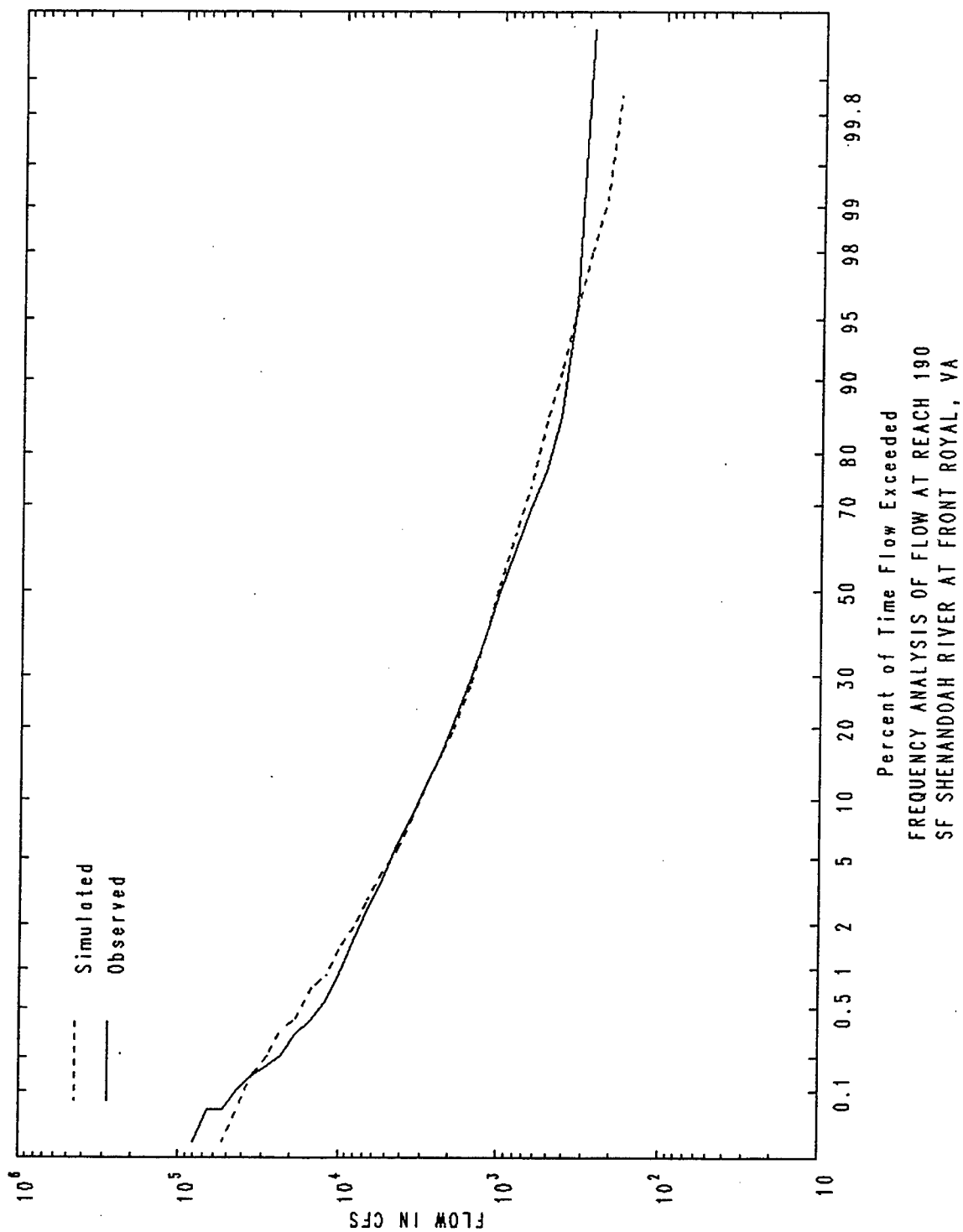
Simulated Benthic Algae Concentration at Reach 200  
AGCHEM Summary for Shenandoah Basin (FOREST), PERLND 191  
AGCHEM Summary for Shenandoah Basin (Hi-Till), PERLND 192  
AGCHEM Summary for Shenandoah Basin (Low-Till), PERLND 193  
AGCHEM Summary for Shenandoah Basin (PASTURE), PERLND 194  
AGCHEM Summary for Shenandoah Basin (HAY), PERLND 196  
AGCHEM Summary for Shenandoah Basin (FOREST), PERLND 201  
AGCHEM Summary for Shenandoah Basin (Hi-Till), PERLND 202  
AGCHEM Summary for Shenandoah Basin (Low-Till), PERLND 203  
AGCHEM Summary for Shenandoah Basin (PASTURE), PERLND 204  
AGCHEM Summary for Shenandoah Basin (HAY), PERLND 206

Per Acre Load Contributed from Each Land Use in Shenandoah Basin (lb/ac)  
Percent of Total Load Contributed from Each Land Use/Source in Shenandoah Basin



SIMULATED AND OBSERVED FLOW AT REACH 190  
SF SHENANDOAH RIVER AT FRONT ROYAL, VA





CHESAPEAKE BAY WATERSHED HYDROLOGIC CALIBRATION  
COMPARISON OF ANNUAL TOTAL OBSERVED vs SIMULATED FLOW

PHASE IV

SF SHENANDOAH RIVER AT FRONT ROYAL, VA (SEGMENT 190)

YEAR	OBSERVED* FLOW (in)	SIMULATED** FLOW (in)
1984	18.60	20.05
1985	16.20	17.10
1986	7.34	7.24
1987	16.10	14.73
1988	7.71	7.06
1989	15.08	16.35
1990	13.58	15.41
1991	11.67	11.63
MEAN	13.29	13.70

\* - Observed Flow at SF Shenandoah River at Front Royal, VA

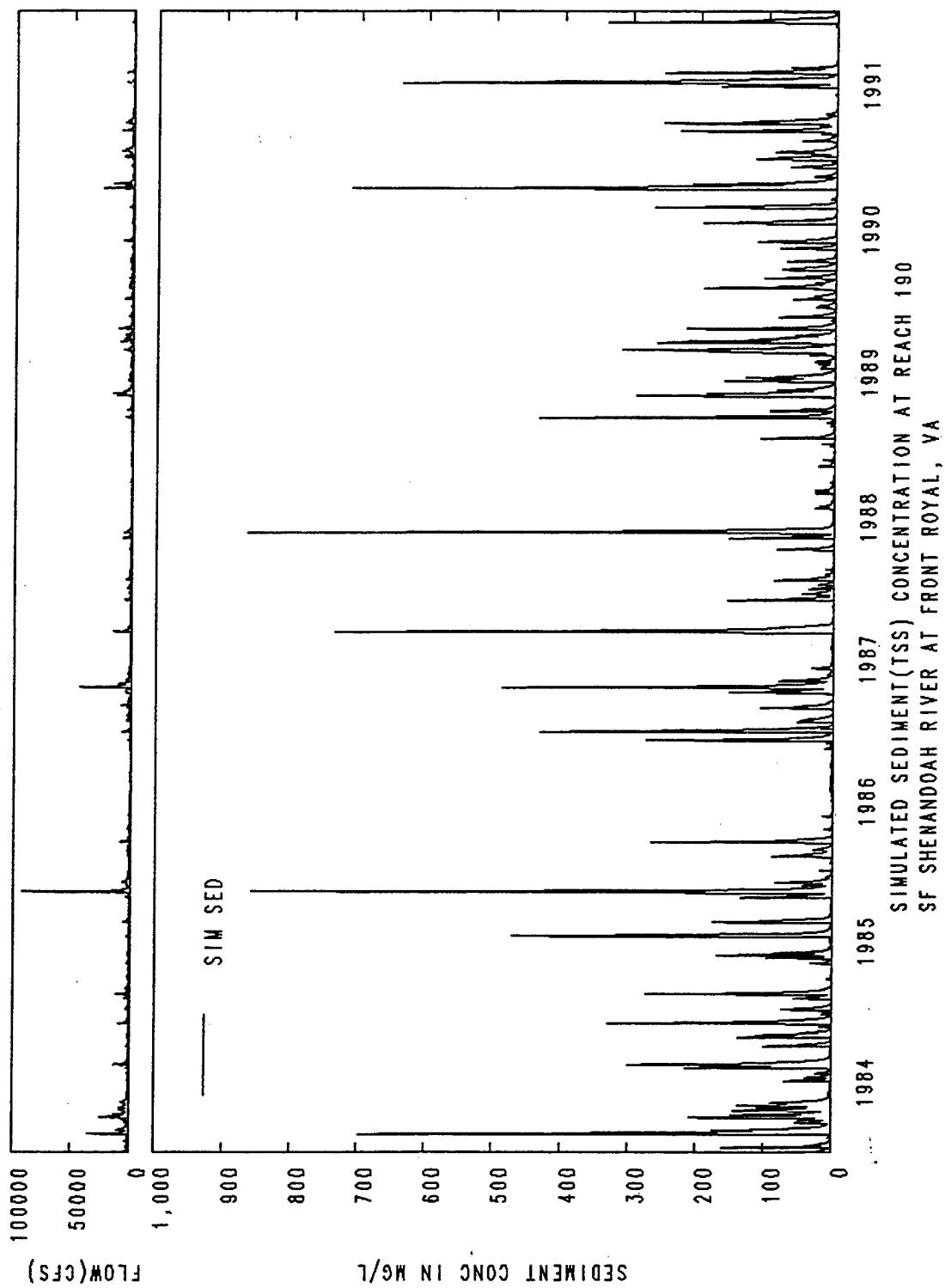
\*\* - Simulated Outflow from RCH 190

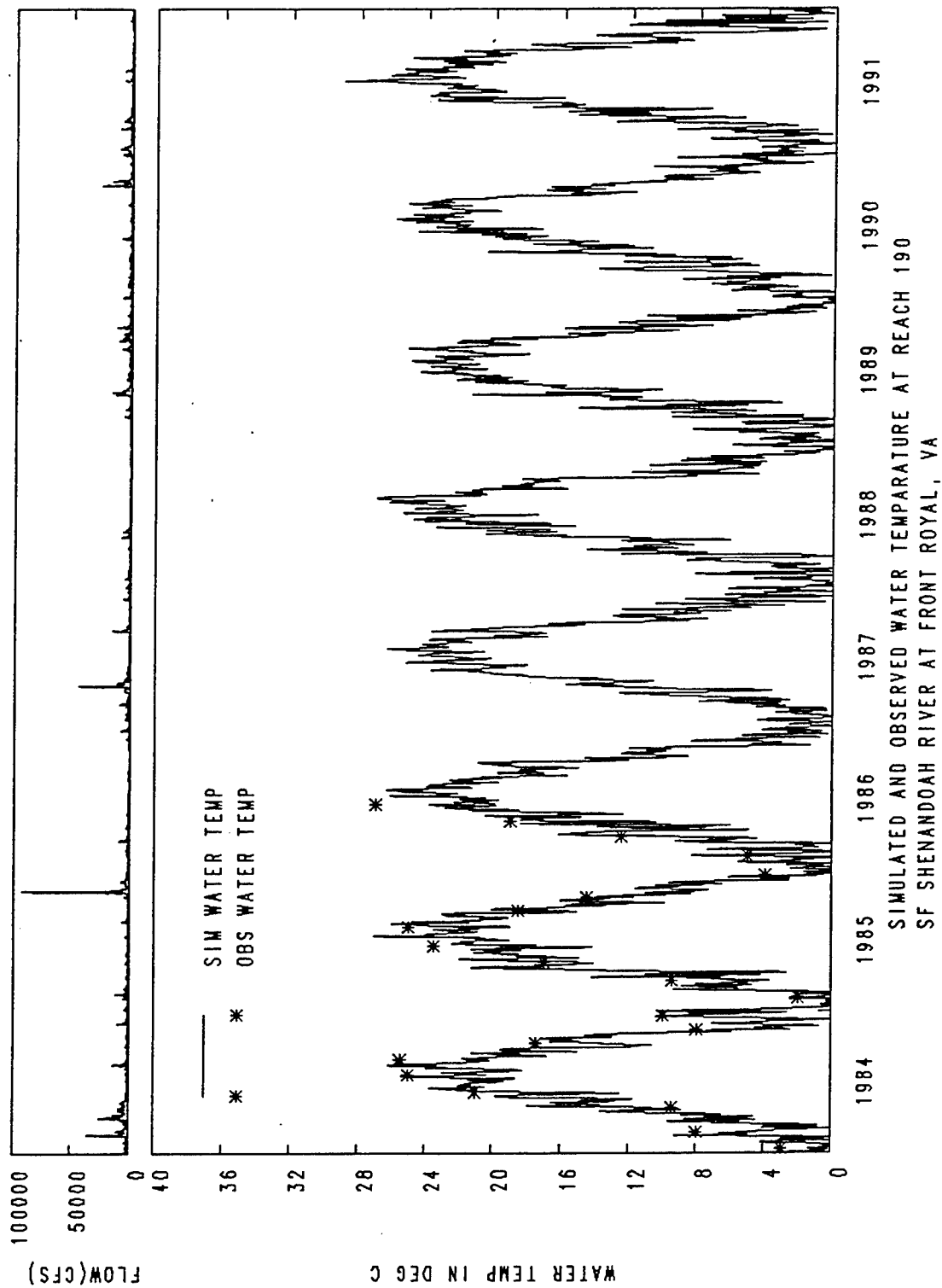
SHENANDOAH RIVER AT MILLVILLE, WV (SEGMENT 200)

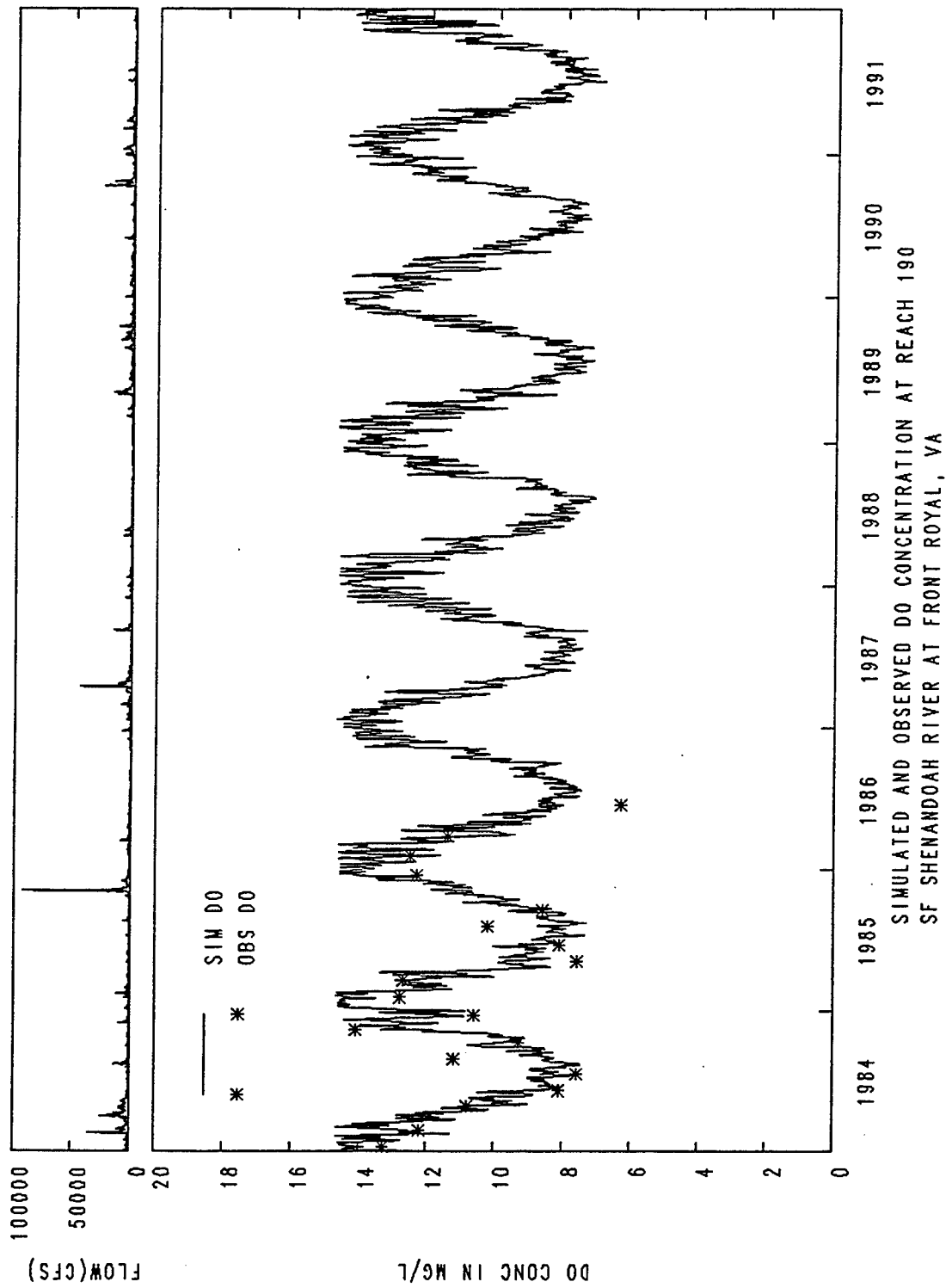
YEAR	OBSERVED* FLOW (in)	SIMULATED** FLOW (in)
1984	17.82	18.27
1985	12.99	14.35
1986	6.92	6.88
1987	13.95	12.09
1988	7.72	6.72
1989	12.02	13.15
1990	11.58	13.78
1991	10.50	9.99
MEAN	11.69	11.90

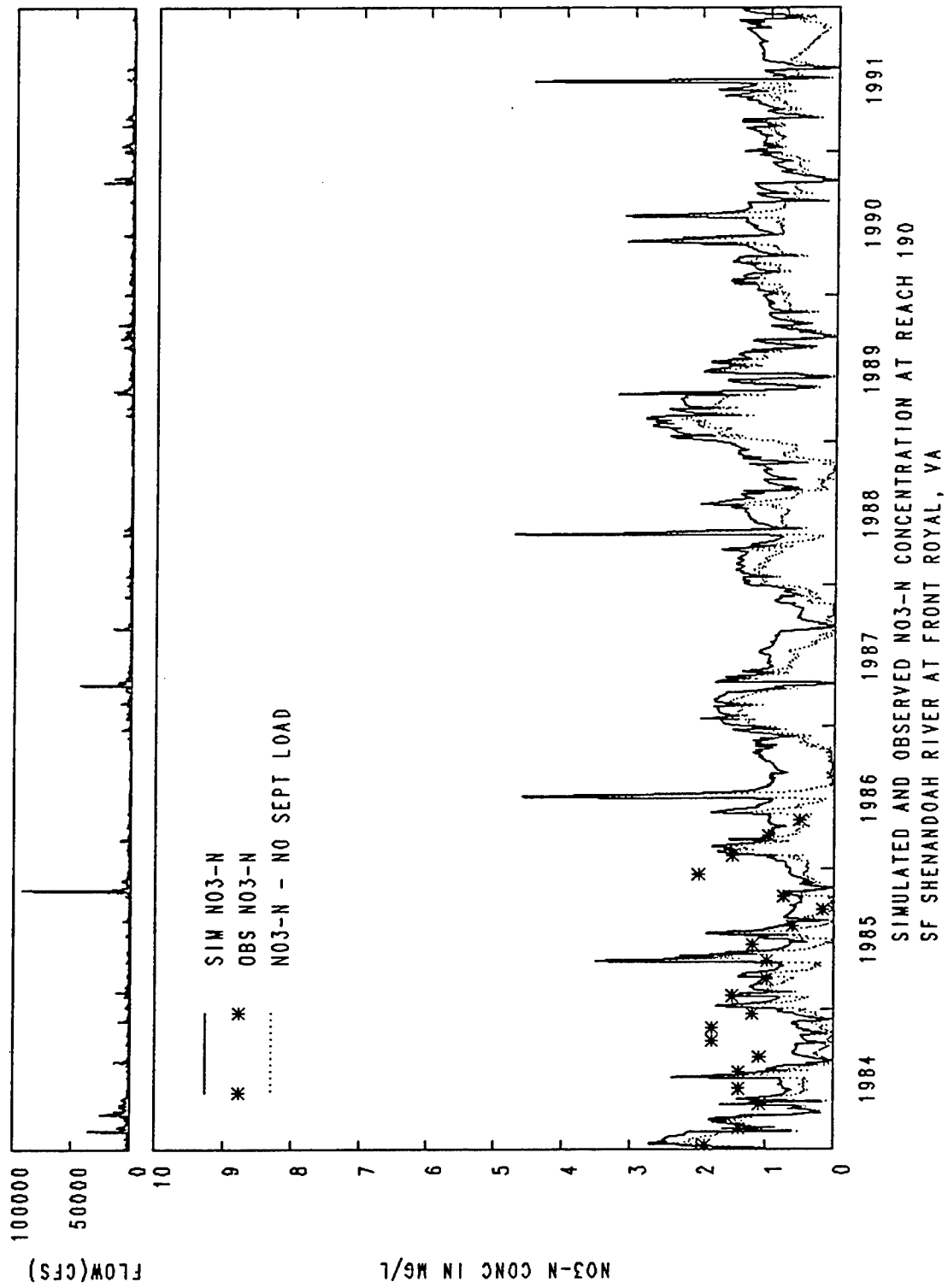
\* - Observed Flow at Shenandoah River at Millville, WV

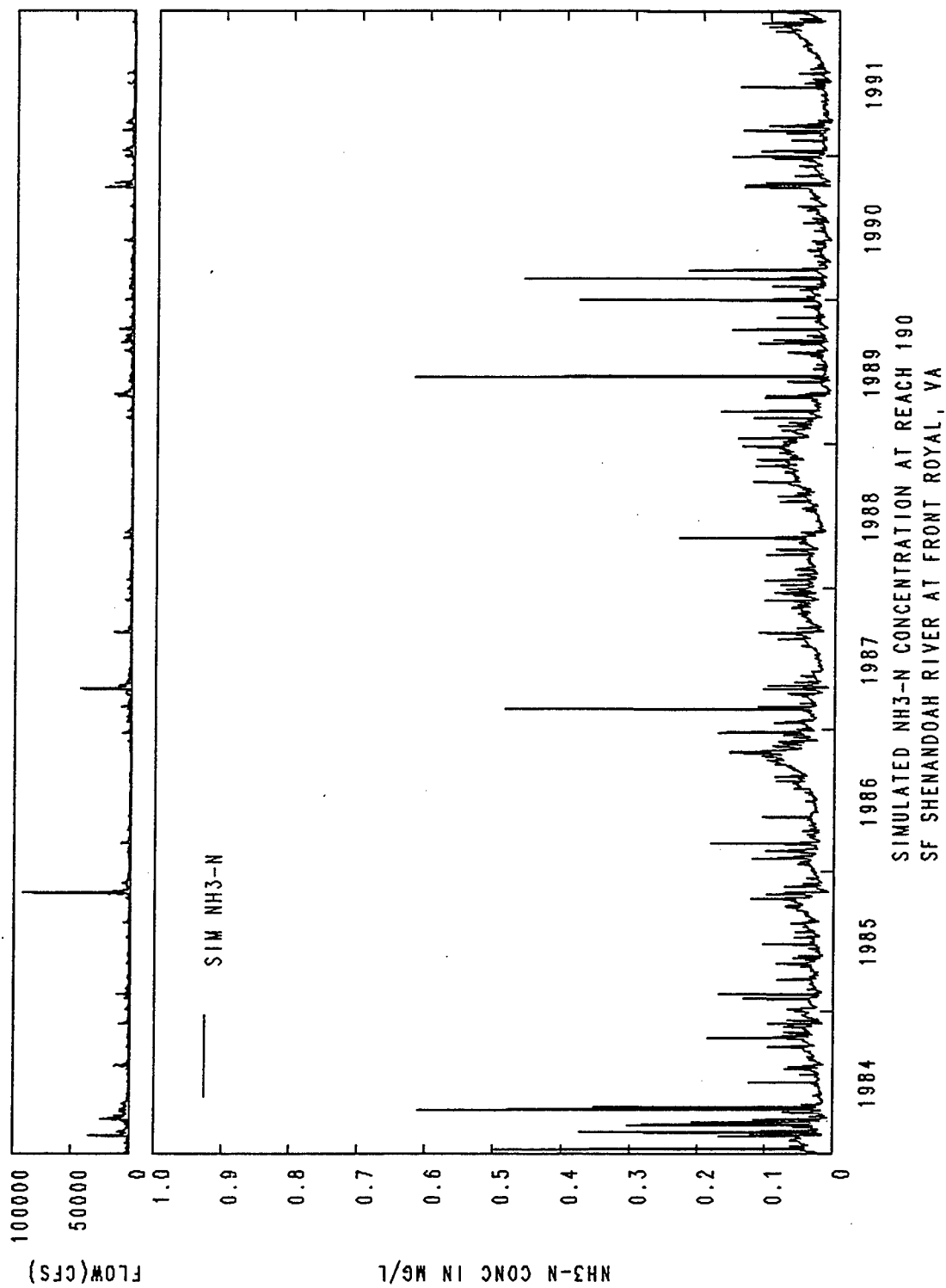
\*\* - Simulated Outflow from RCH 200



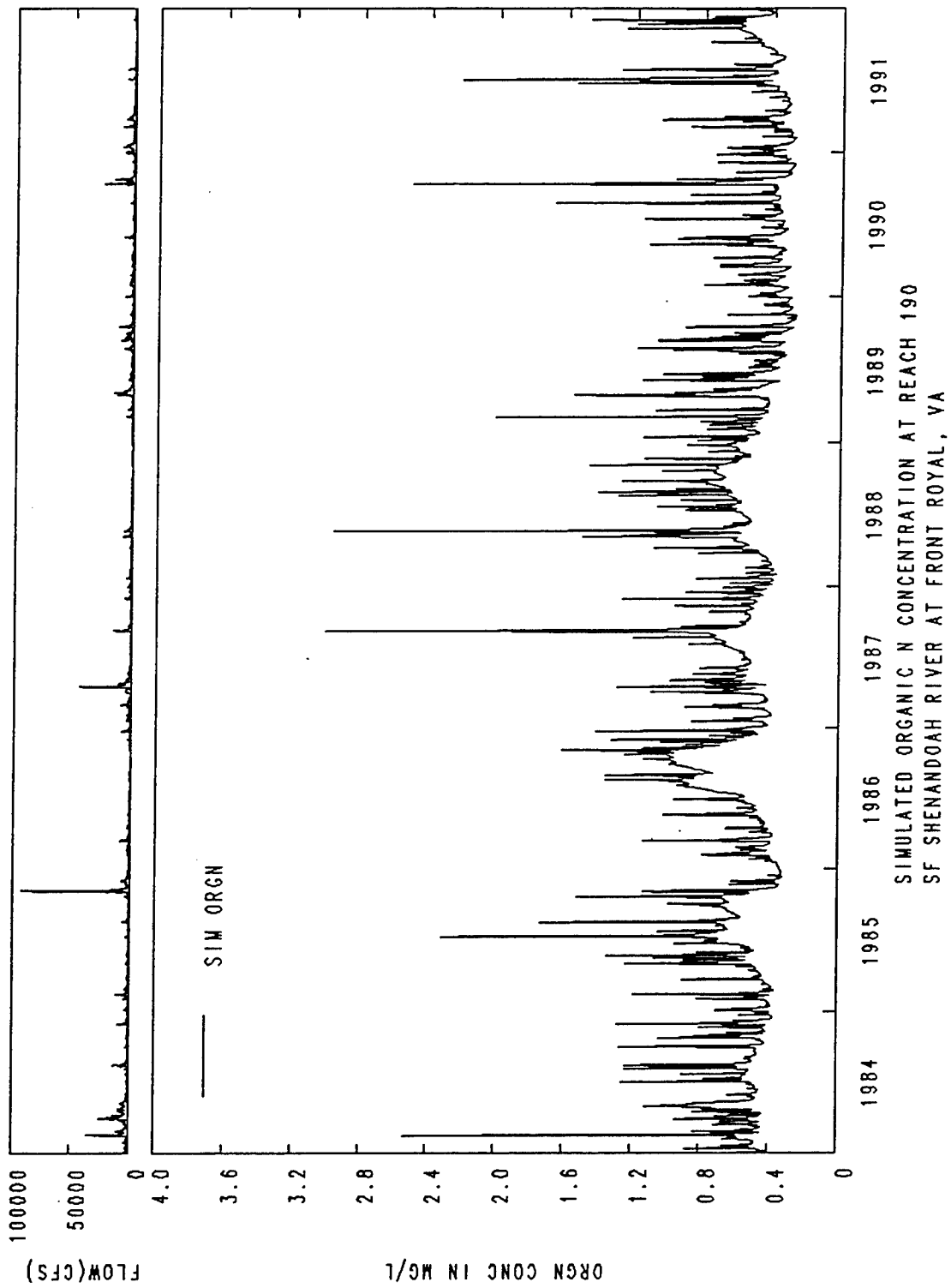


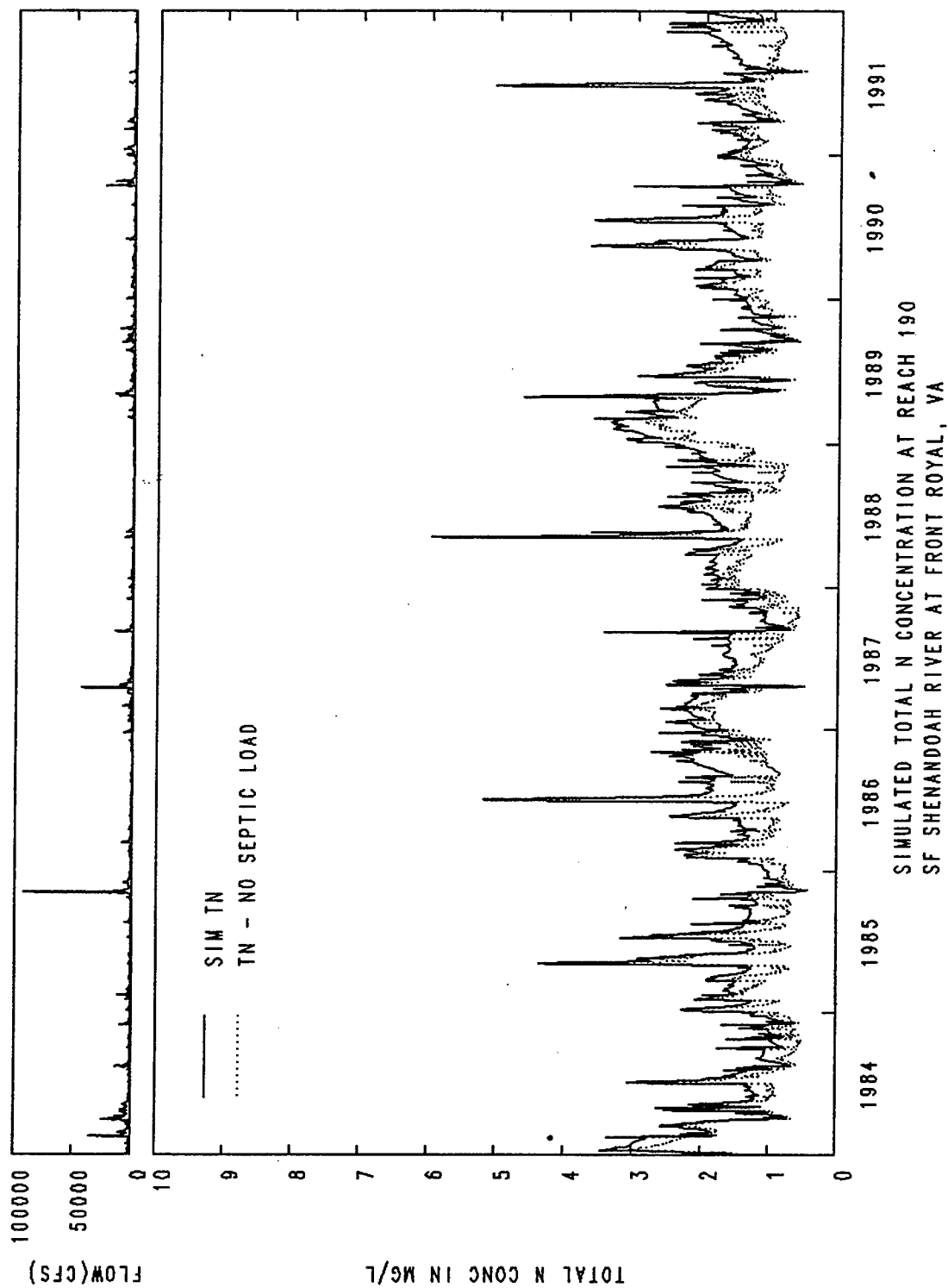


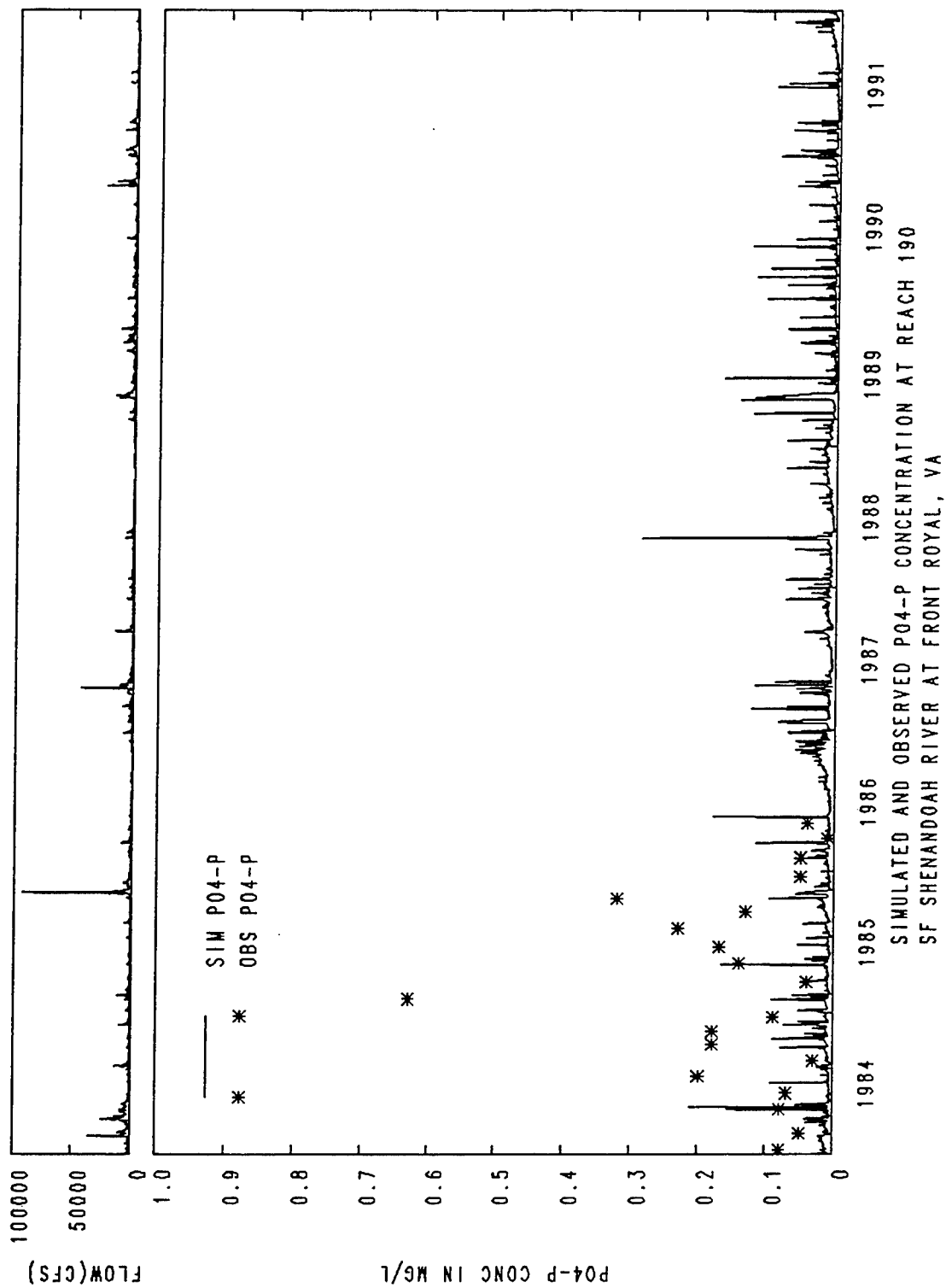


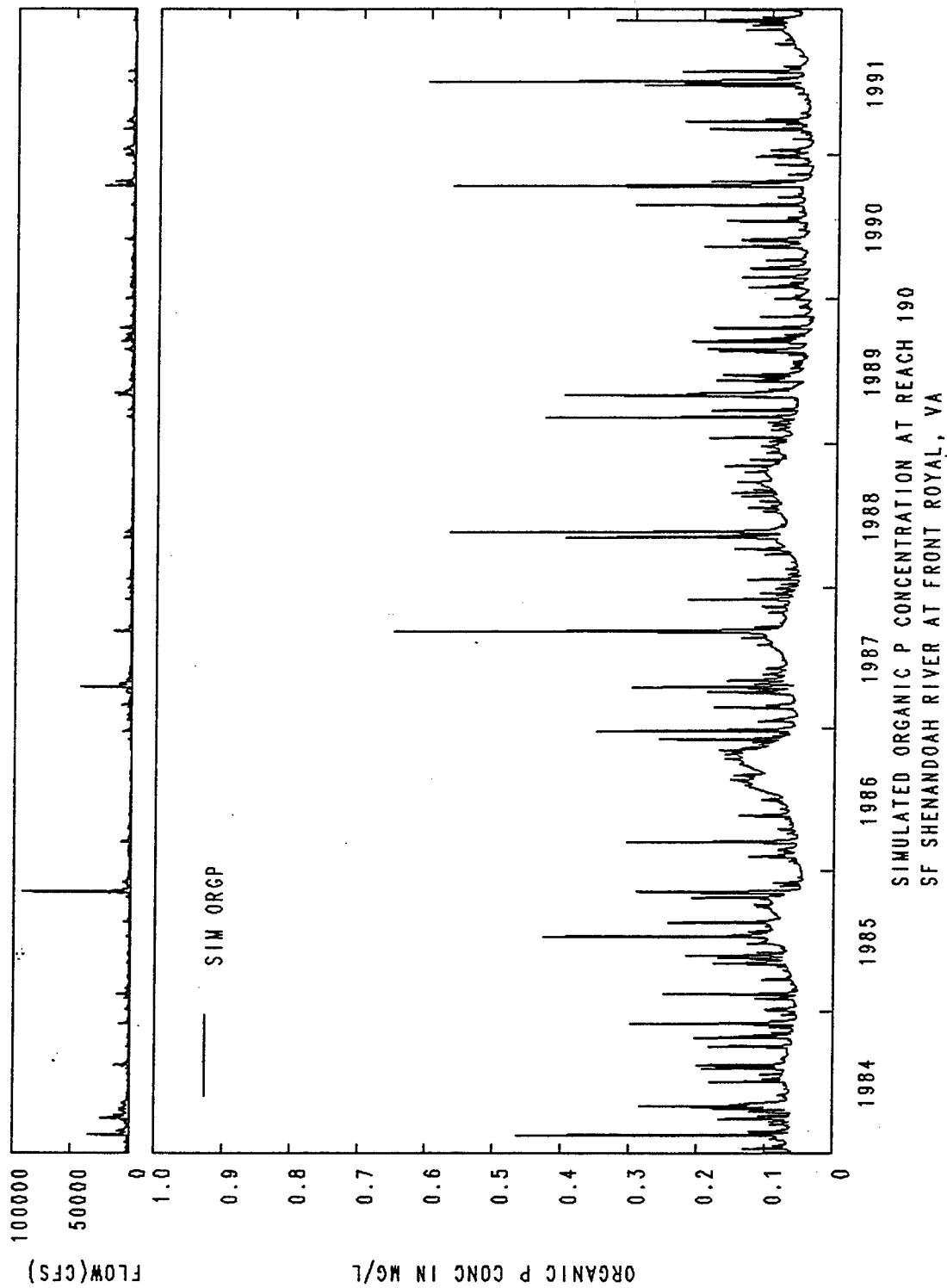


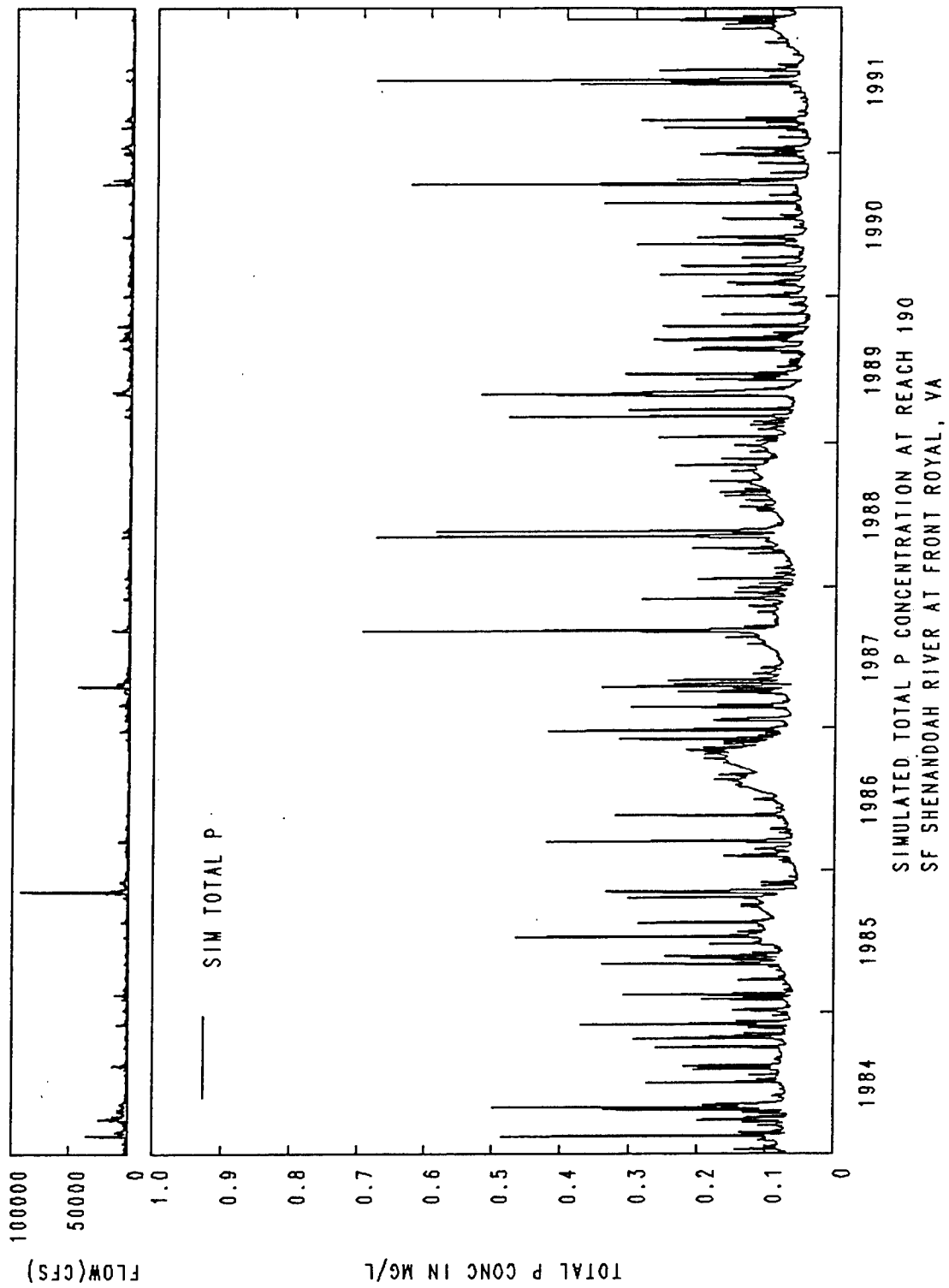
SIMULATED NH3-N CONCENTRATION AT REACH 190  
SF SHENANDOAH RIVER AT FRONT ROYAL, VA

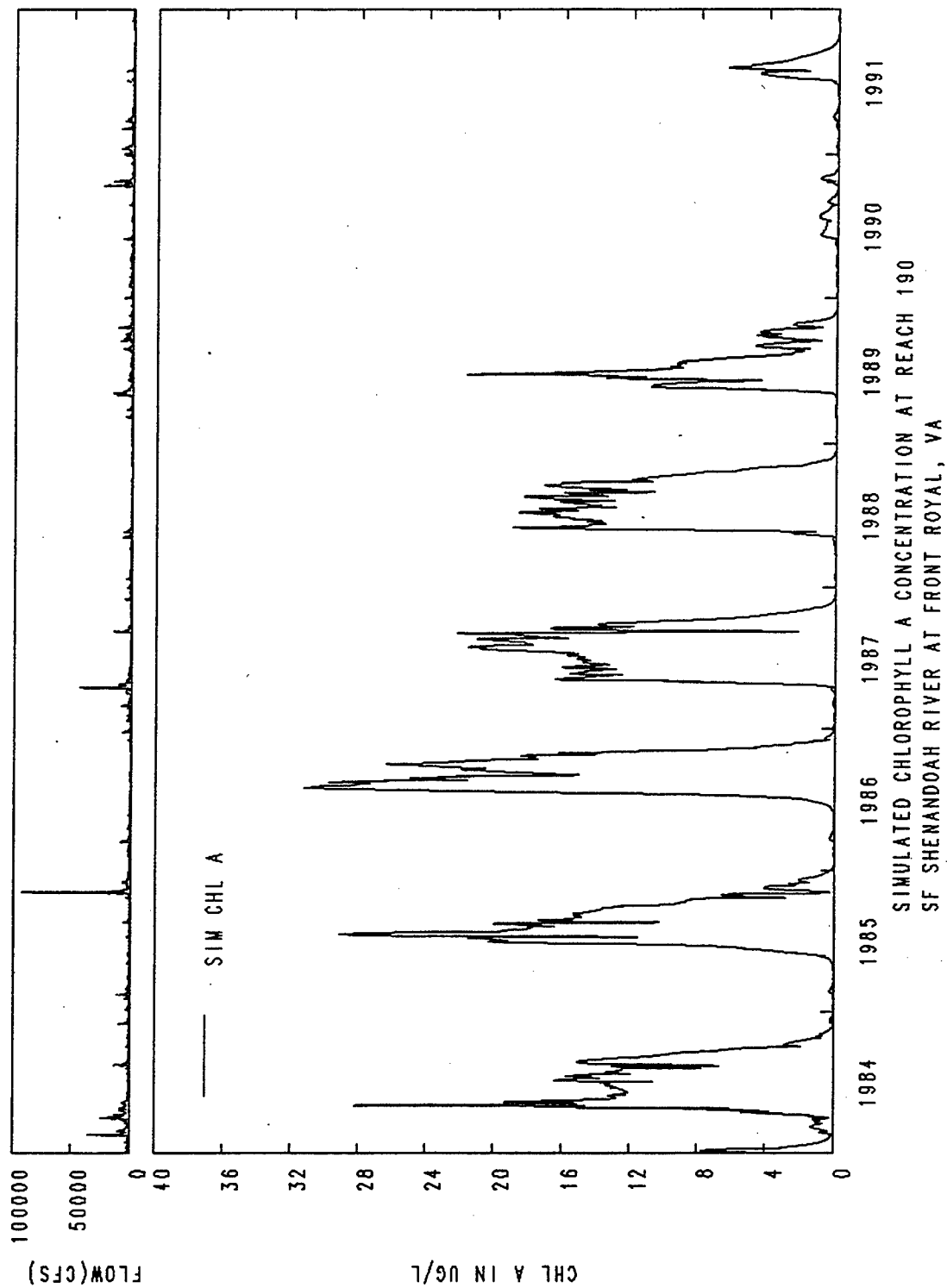


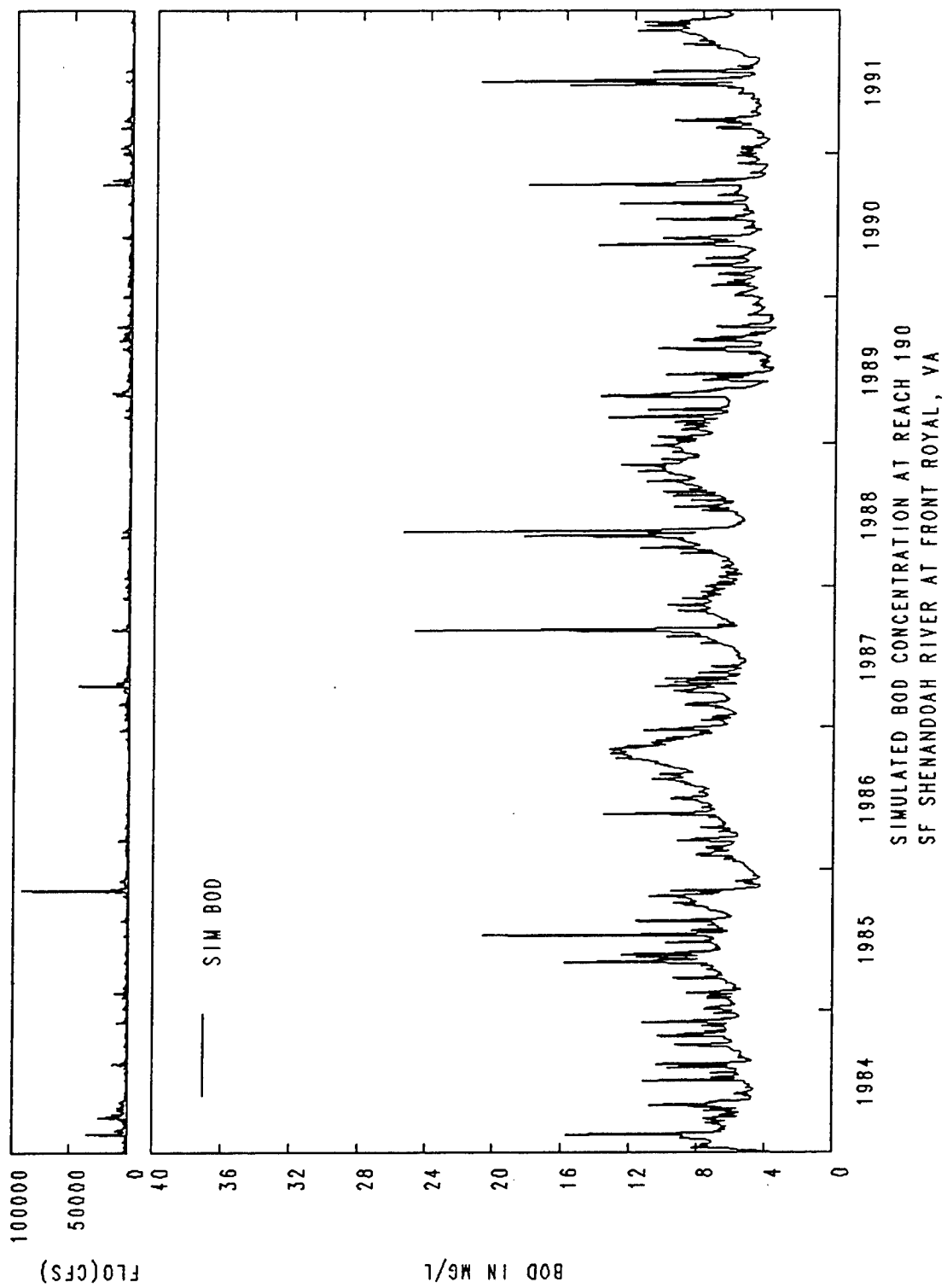


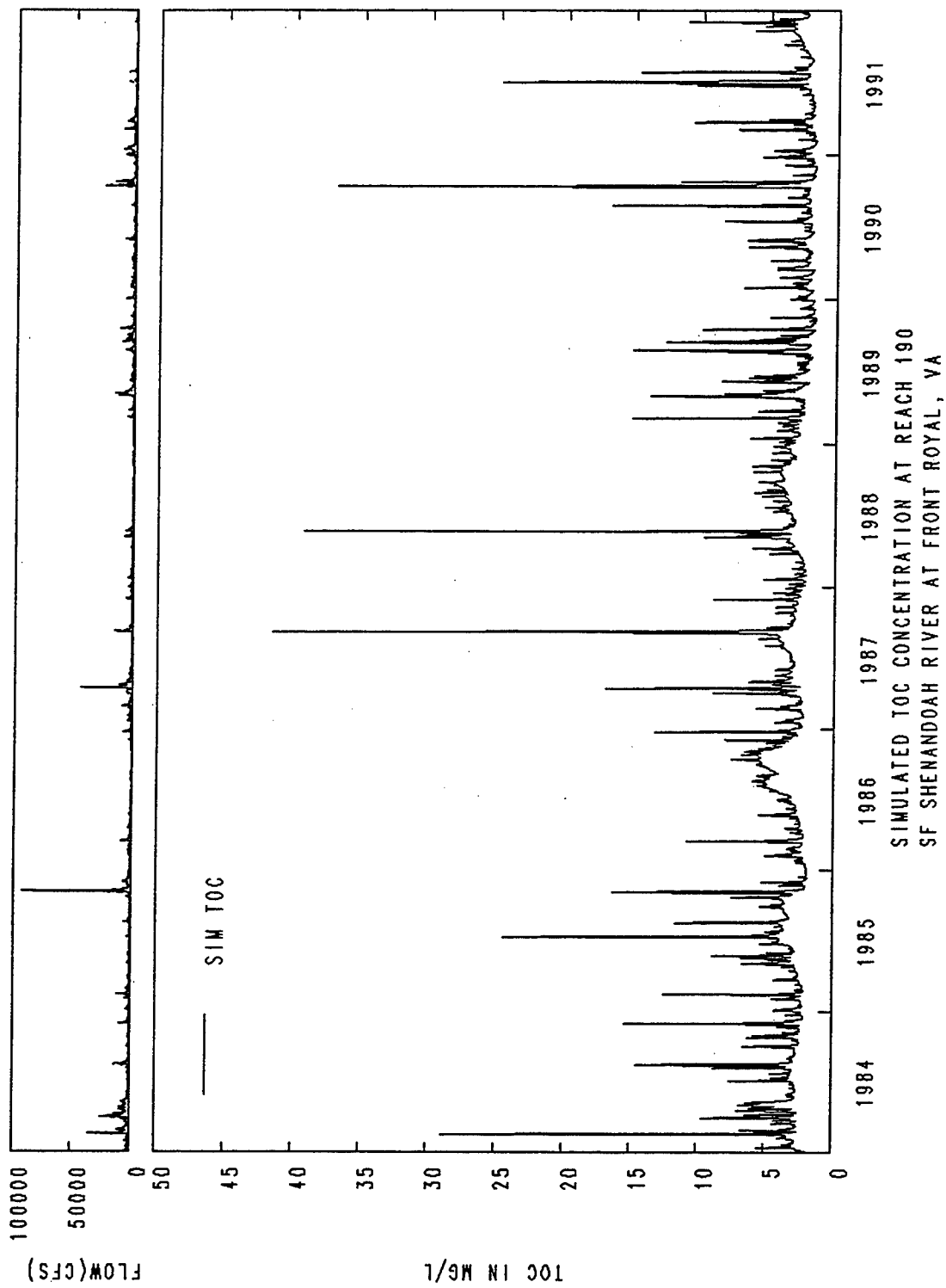


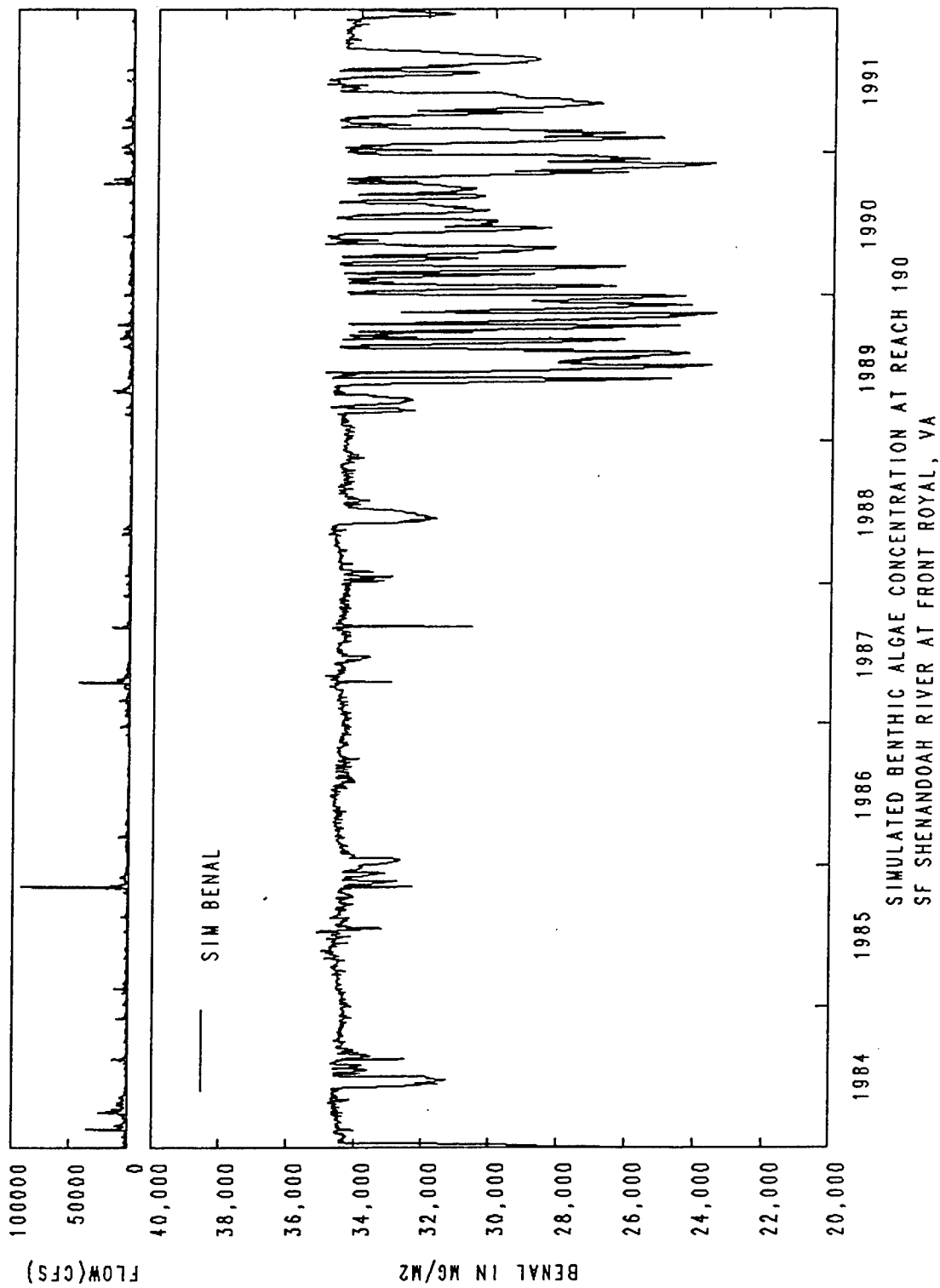


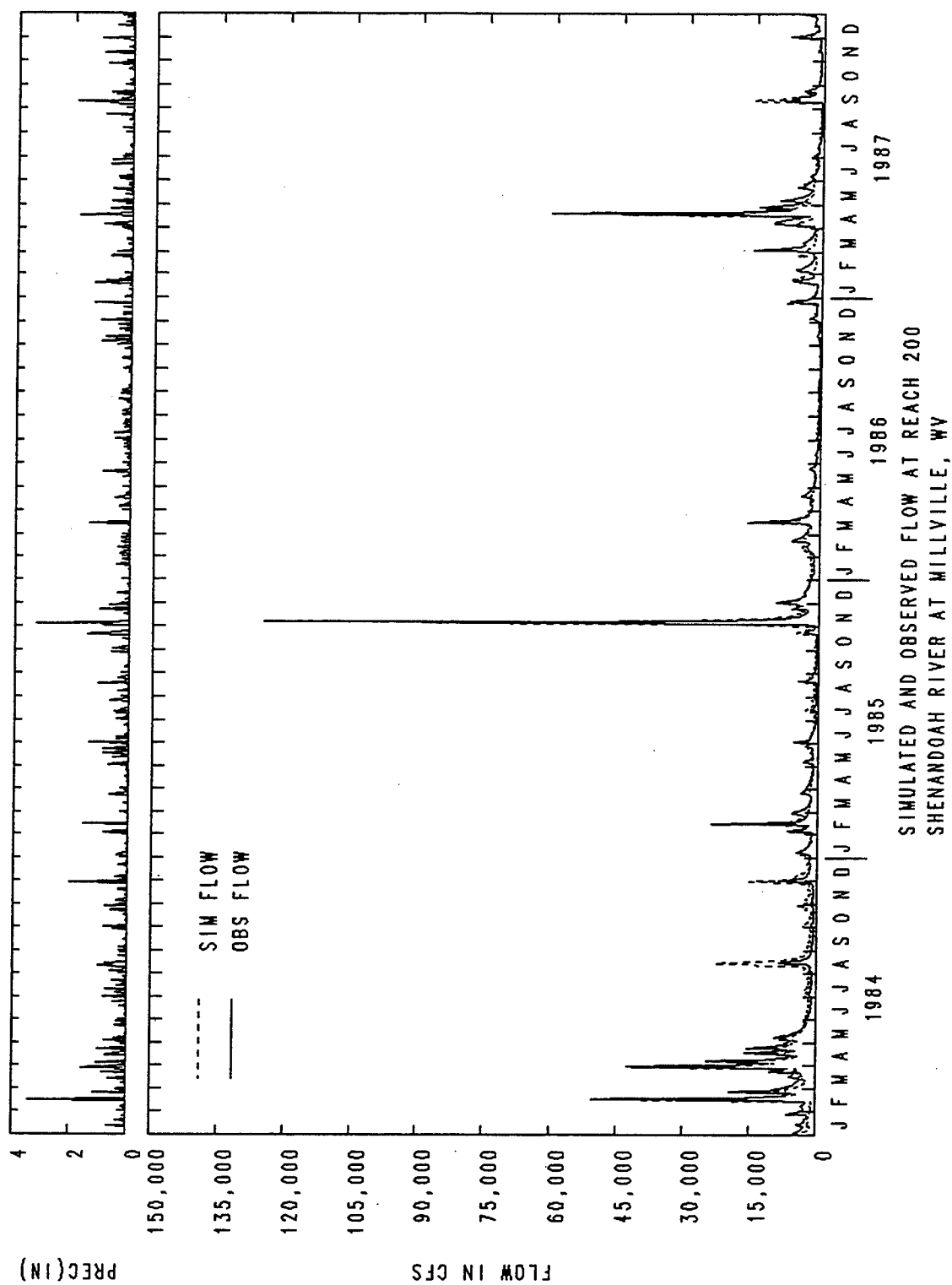


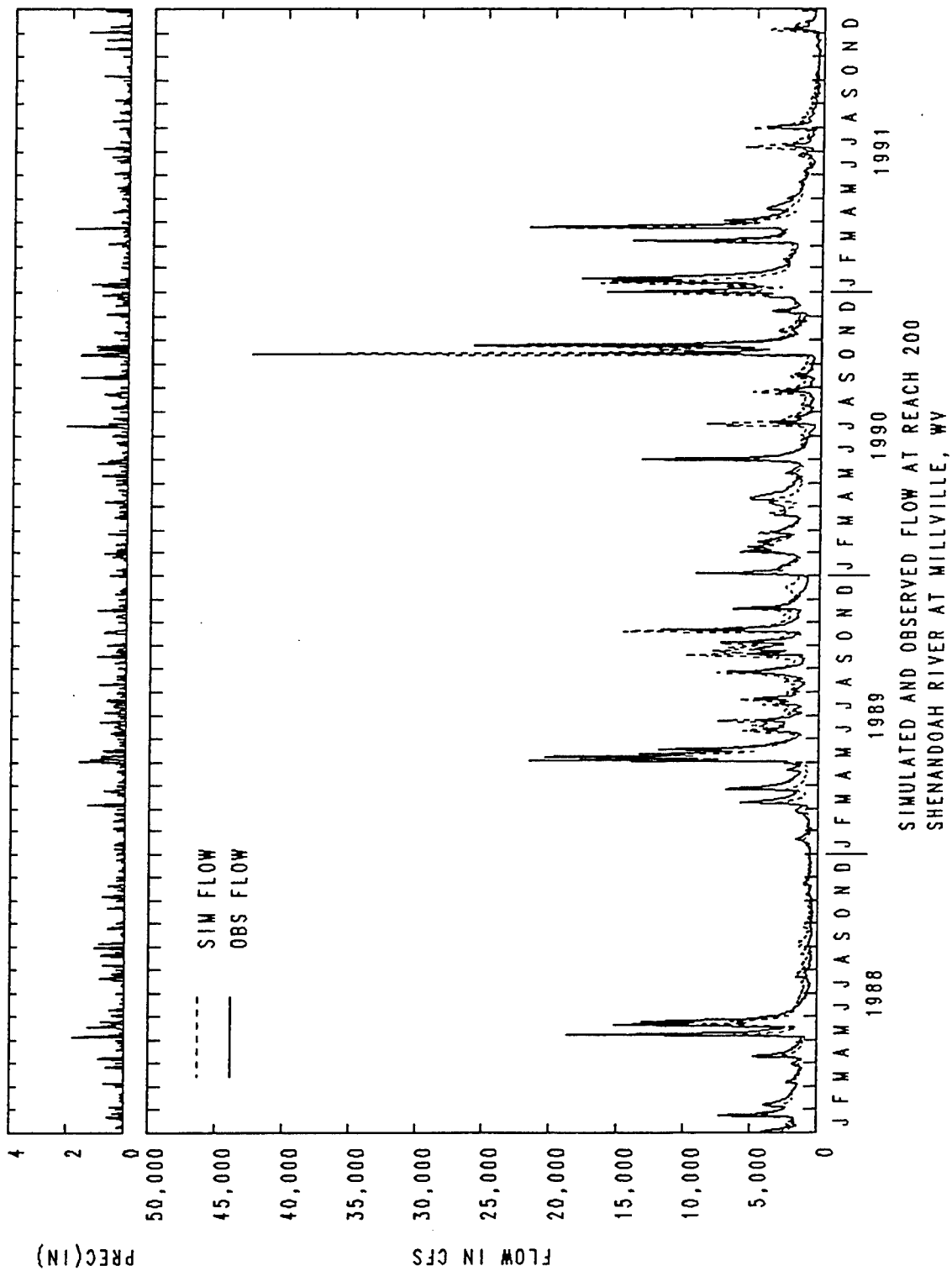


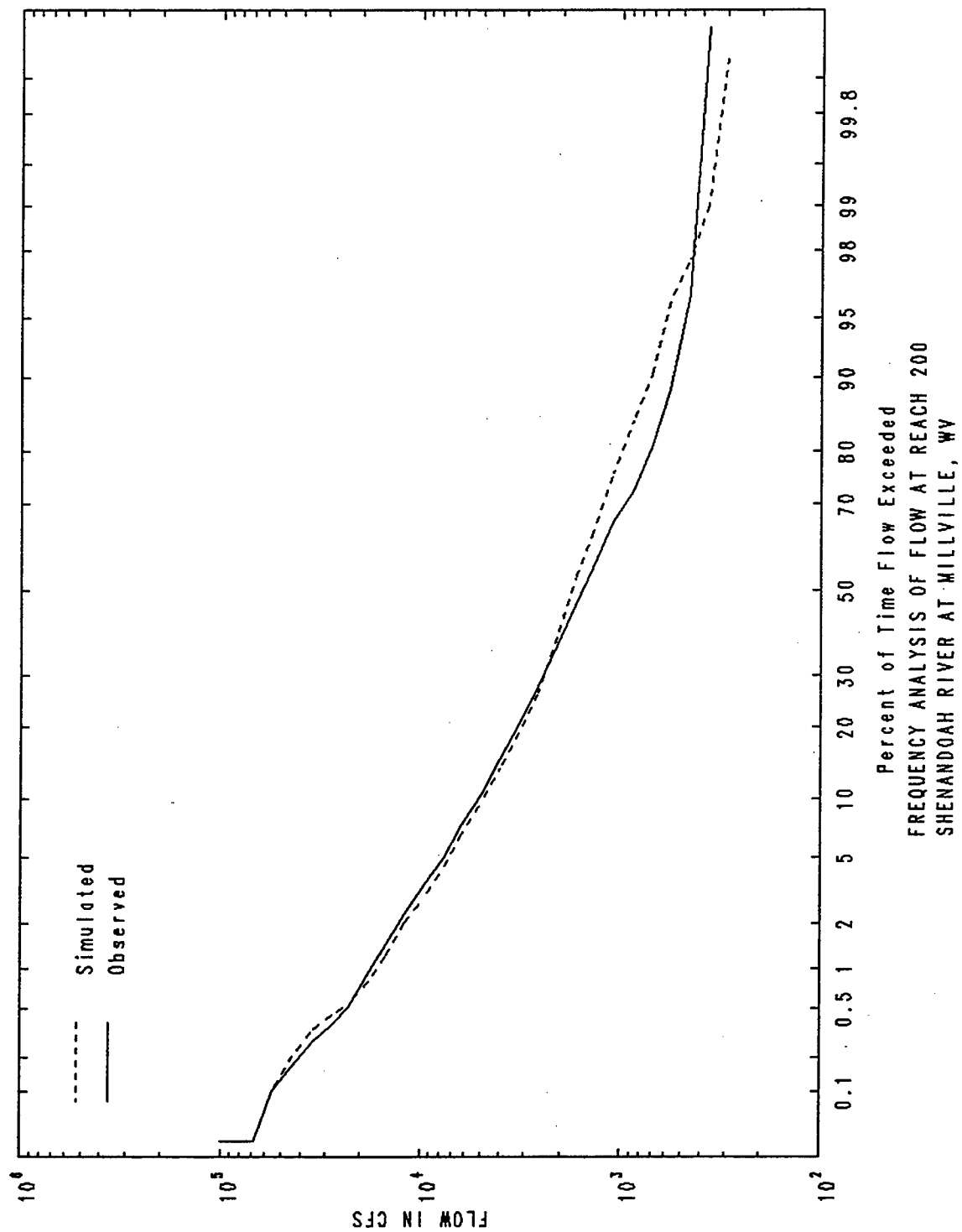


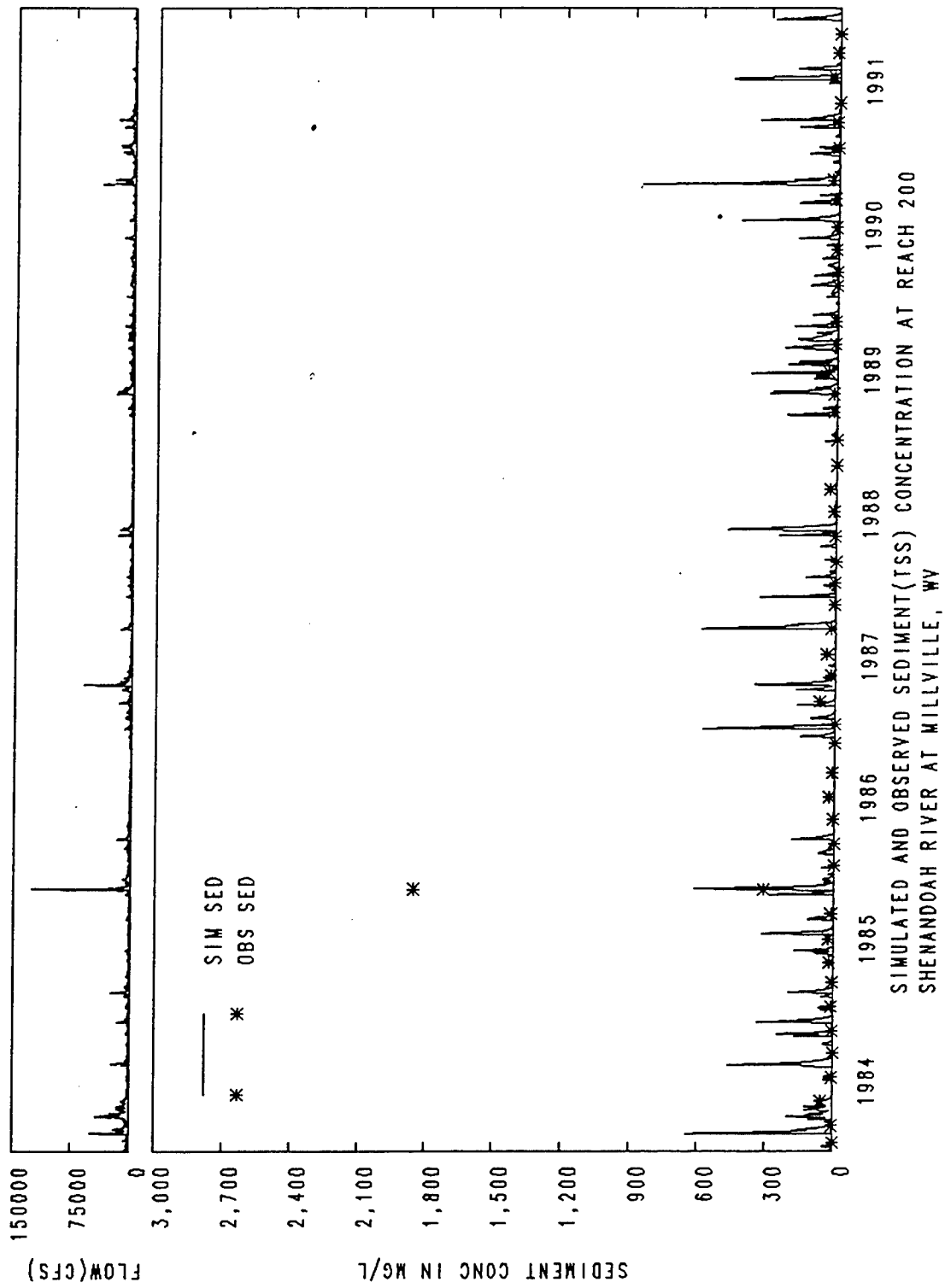


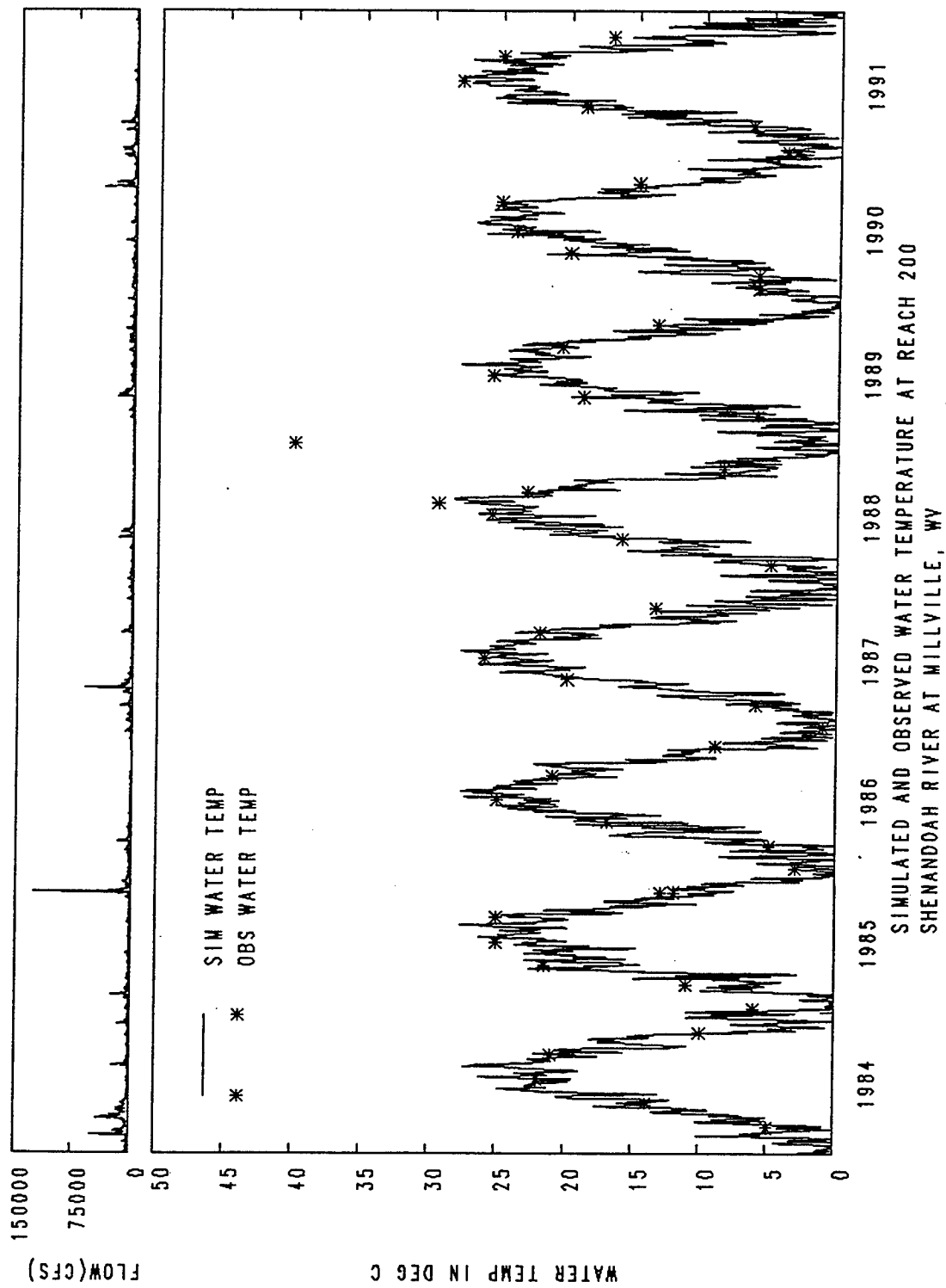


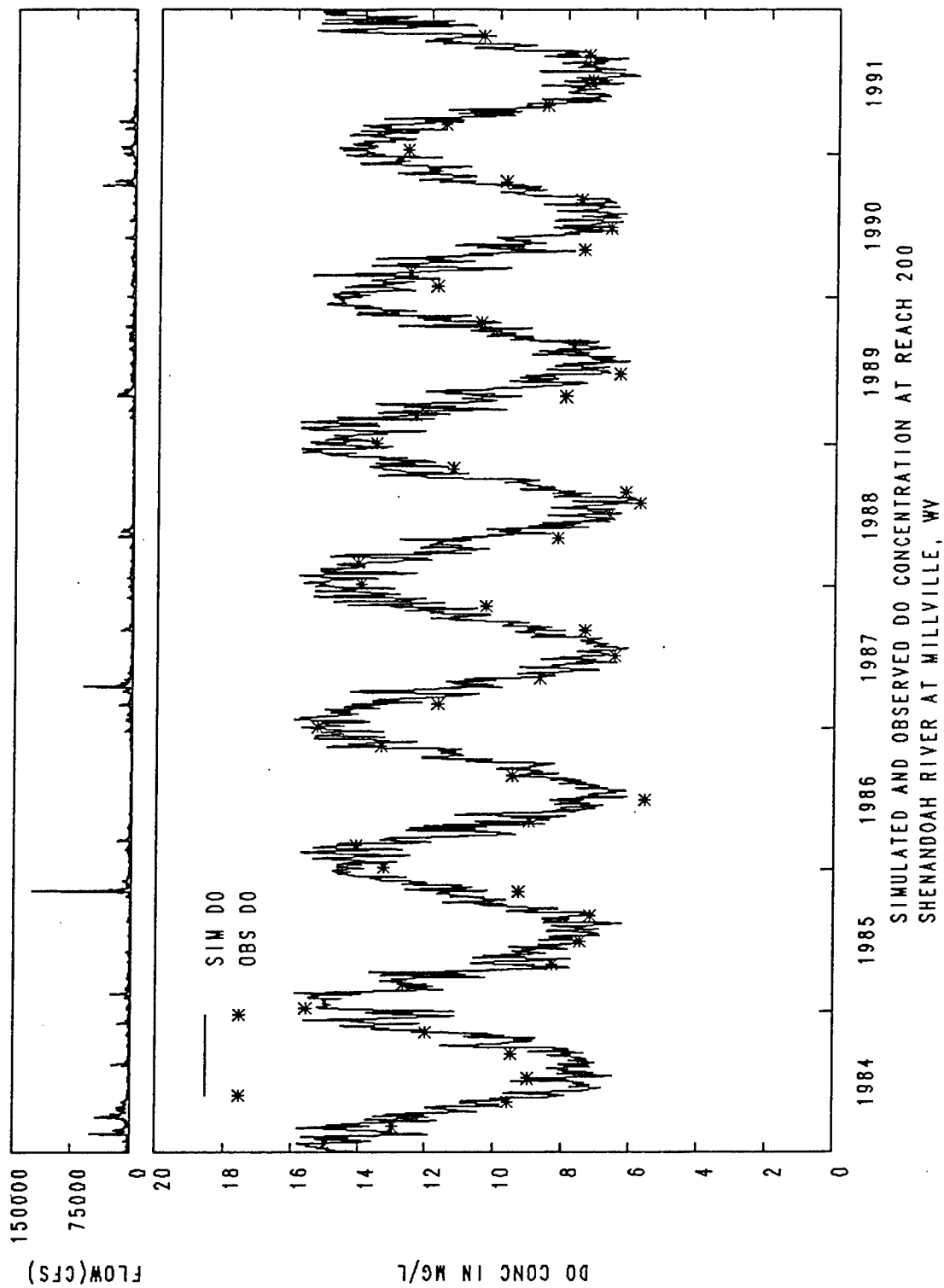


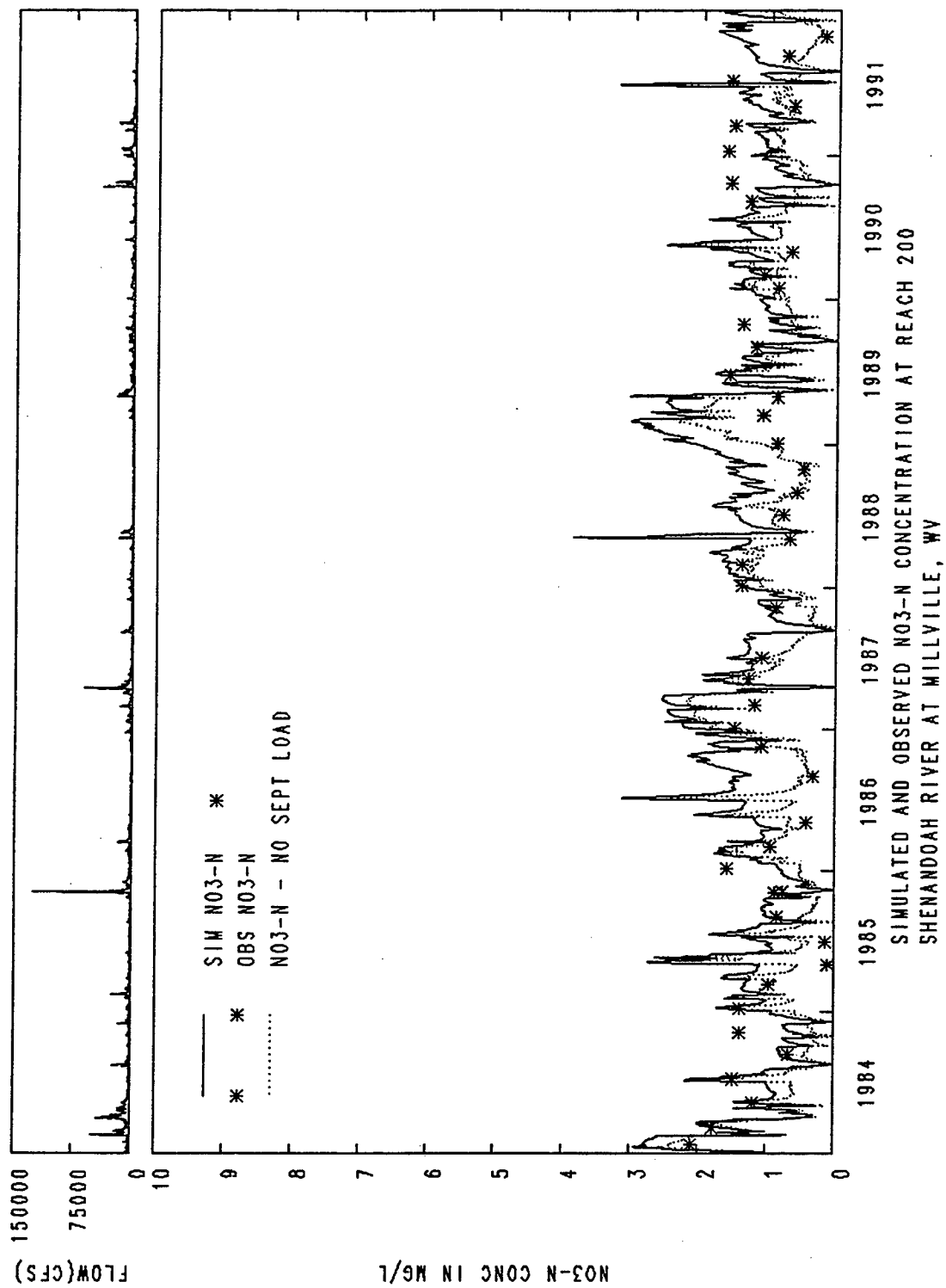


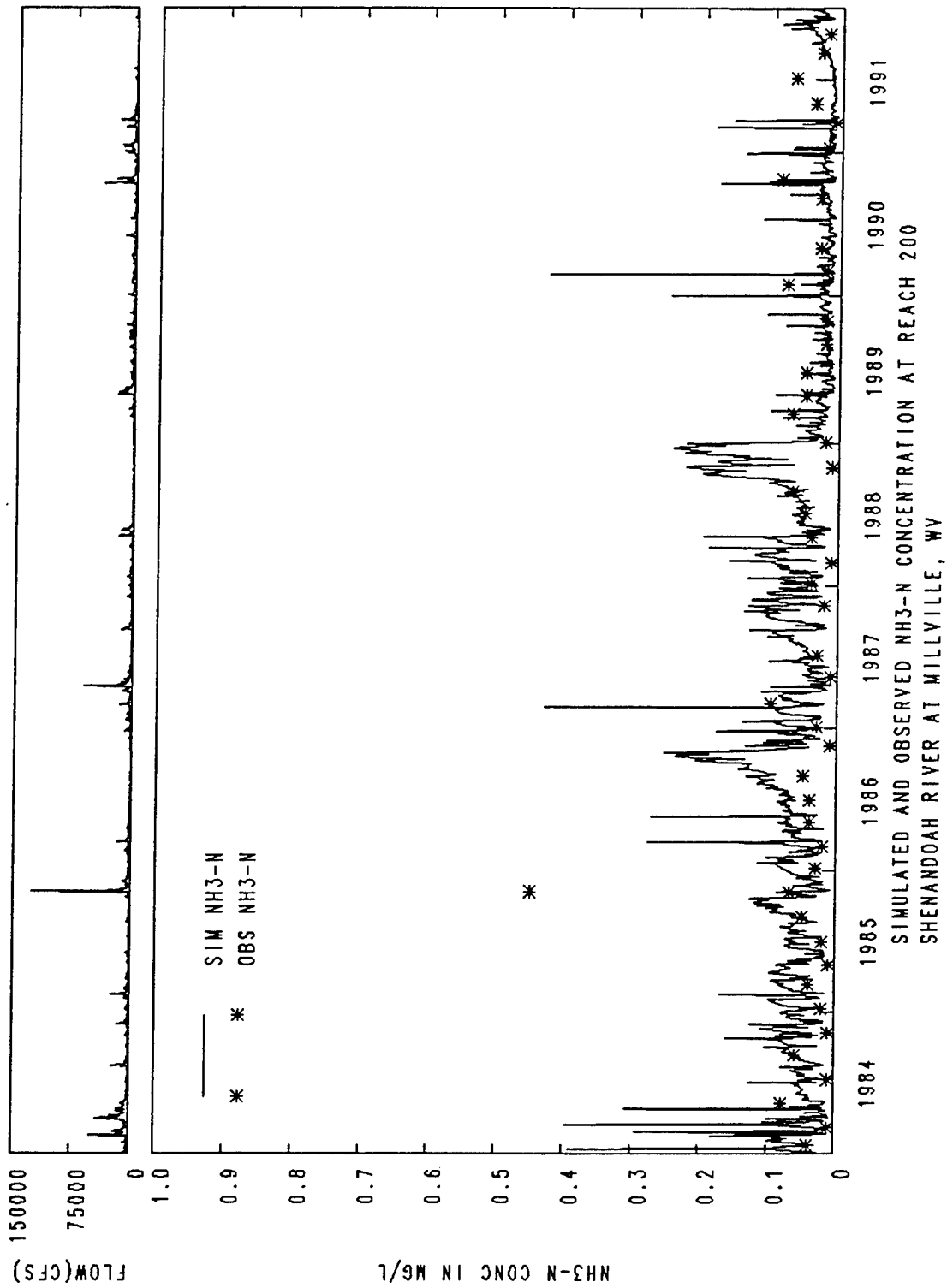


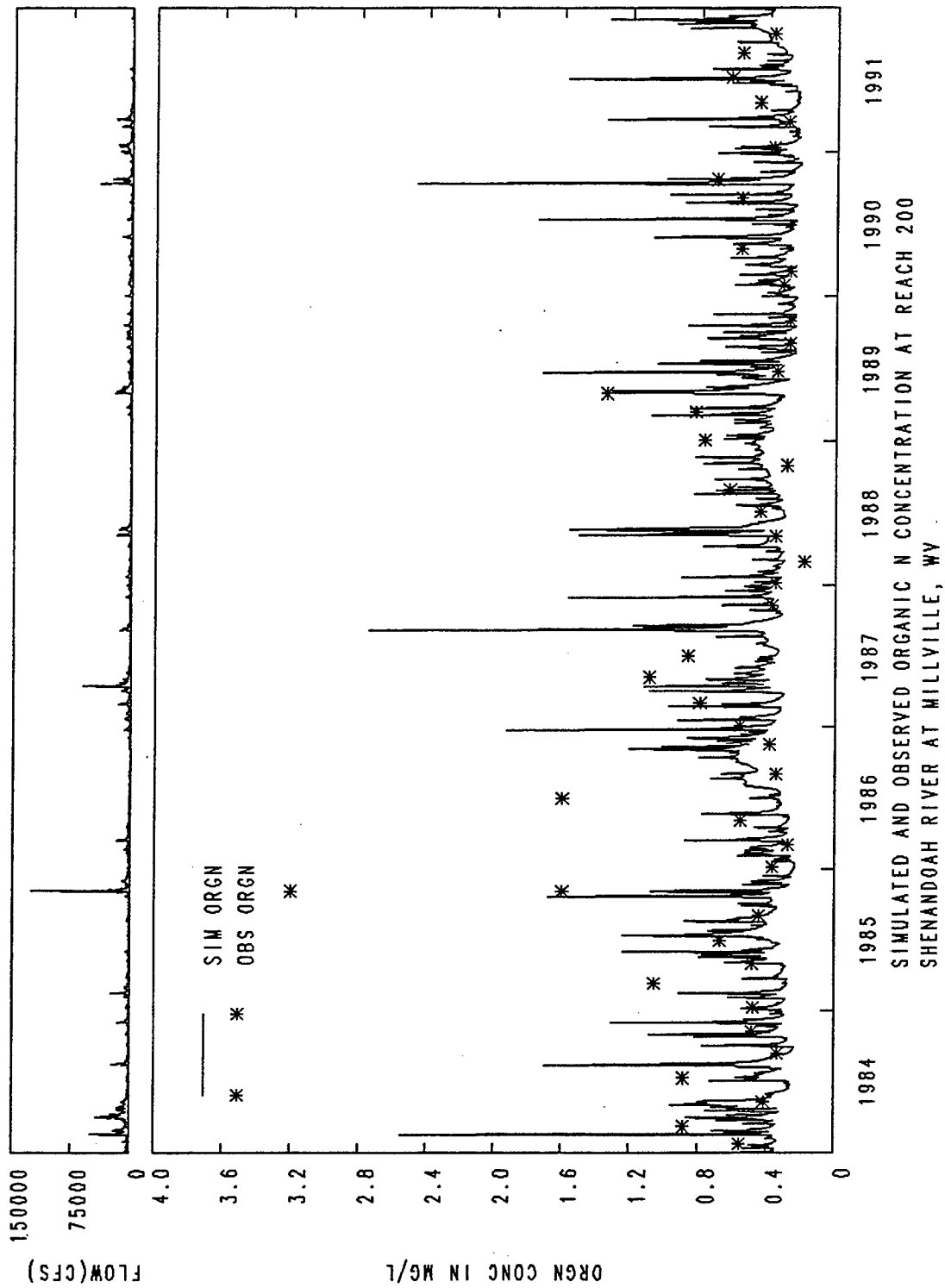


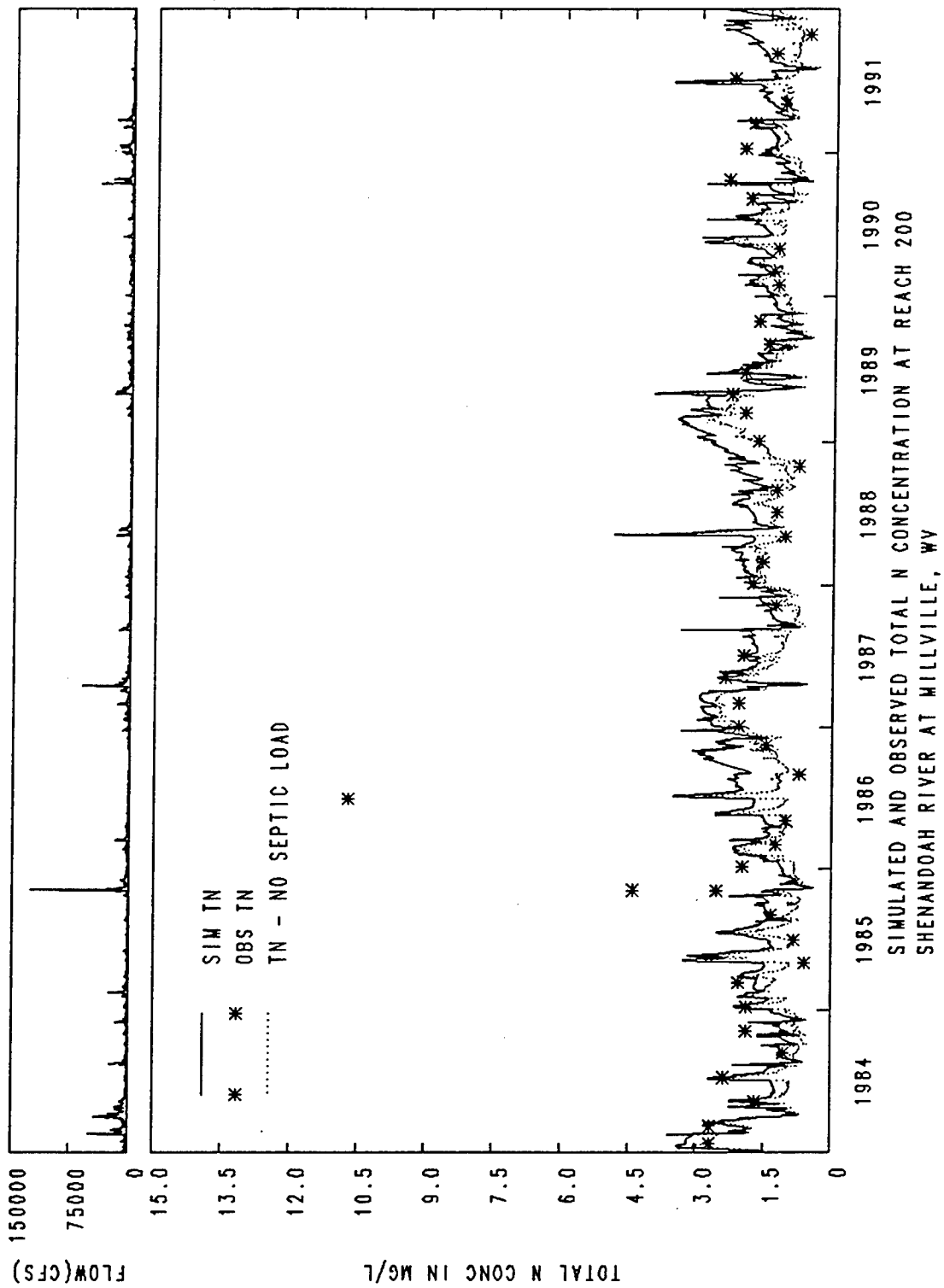


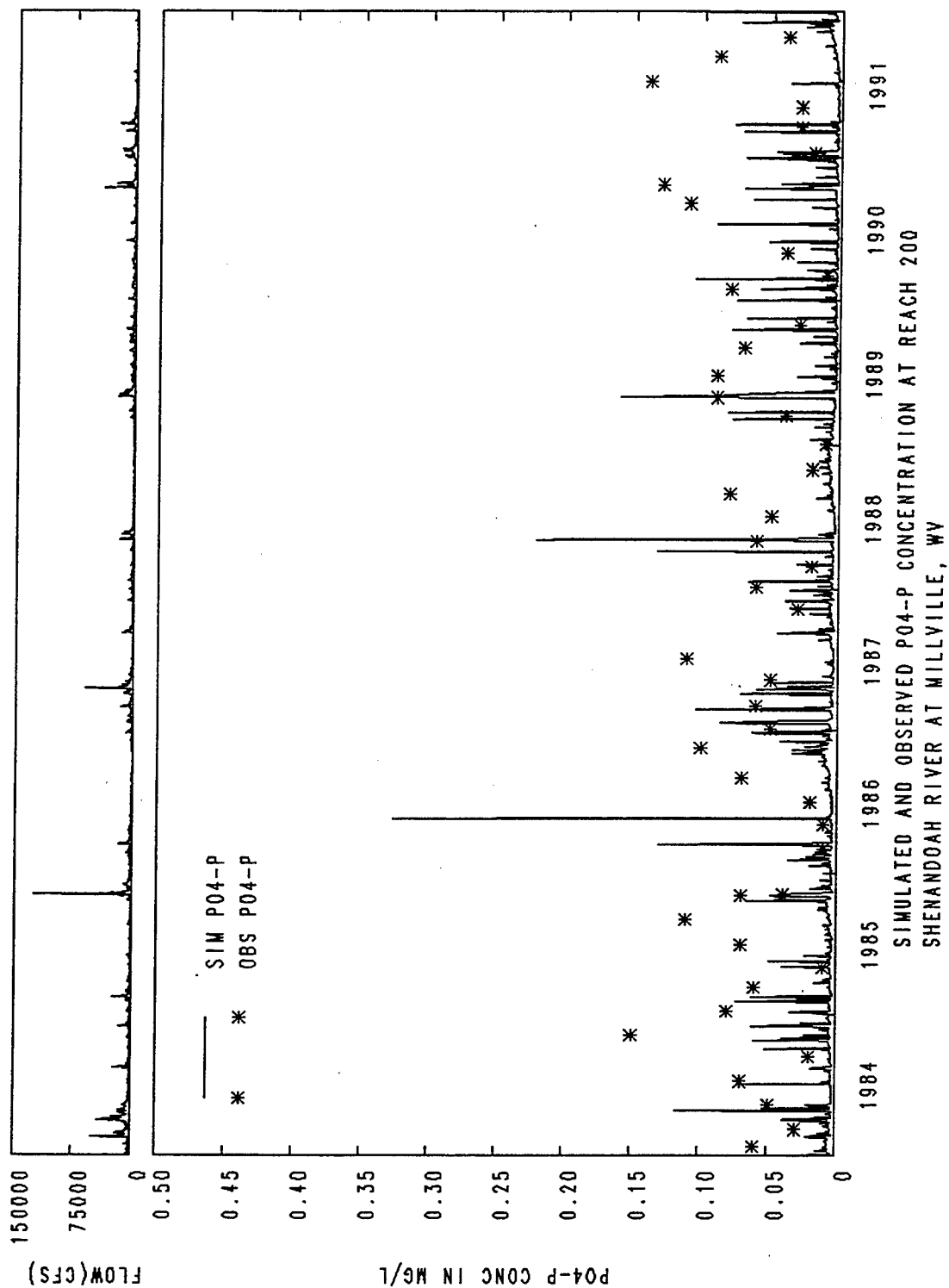


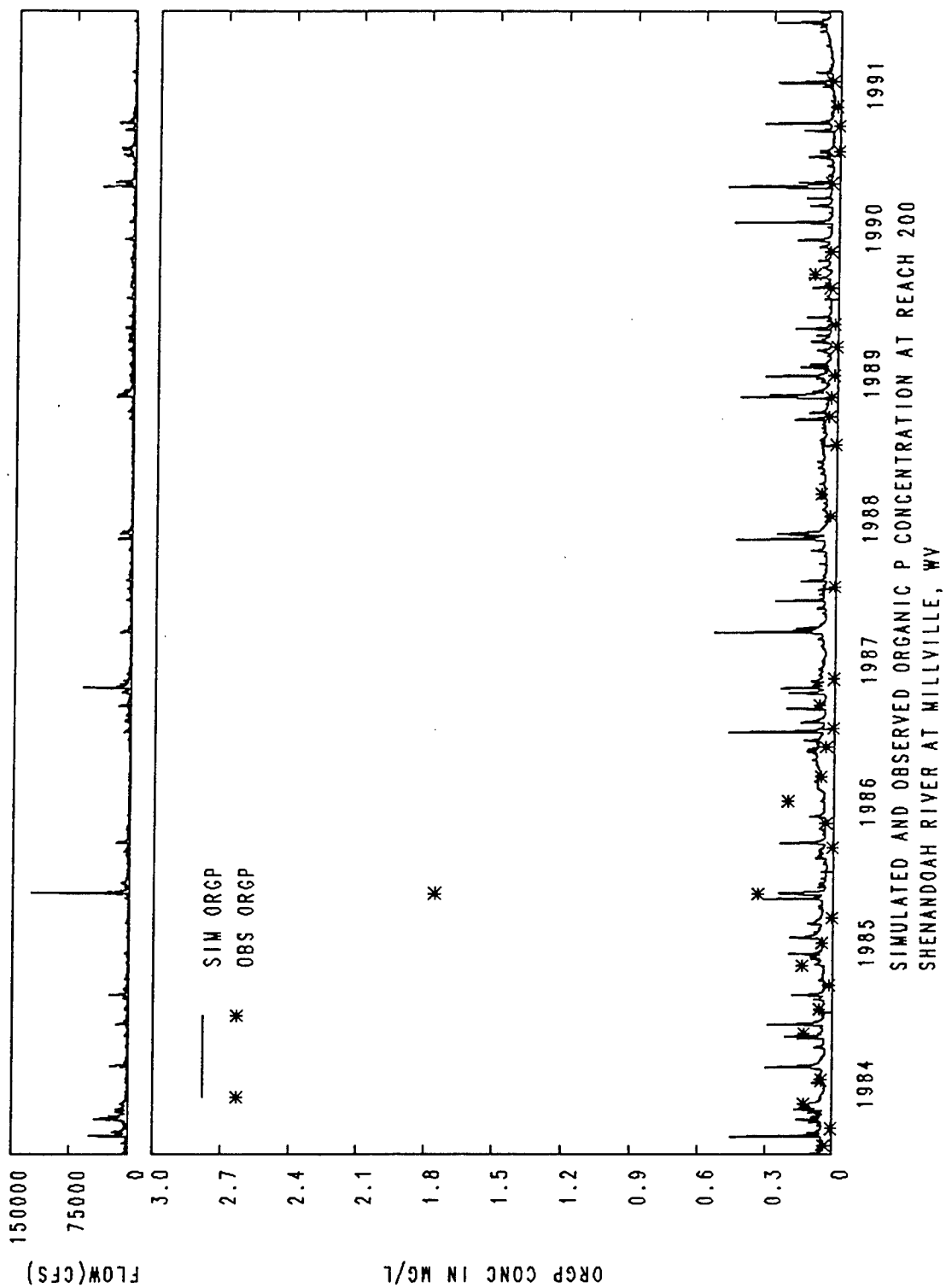


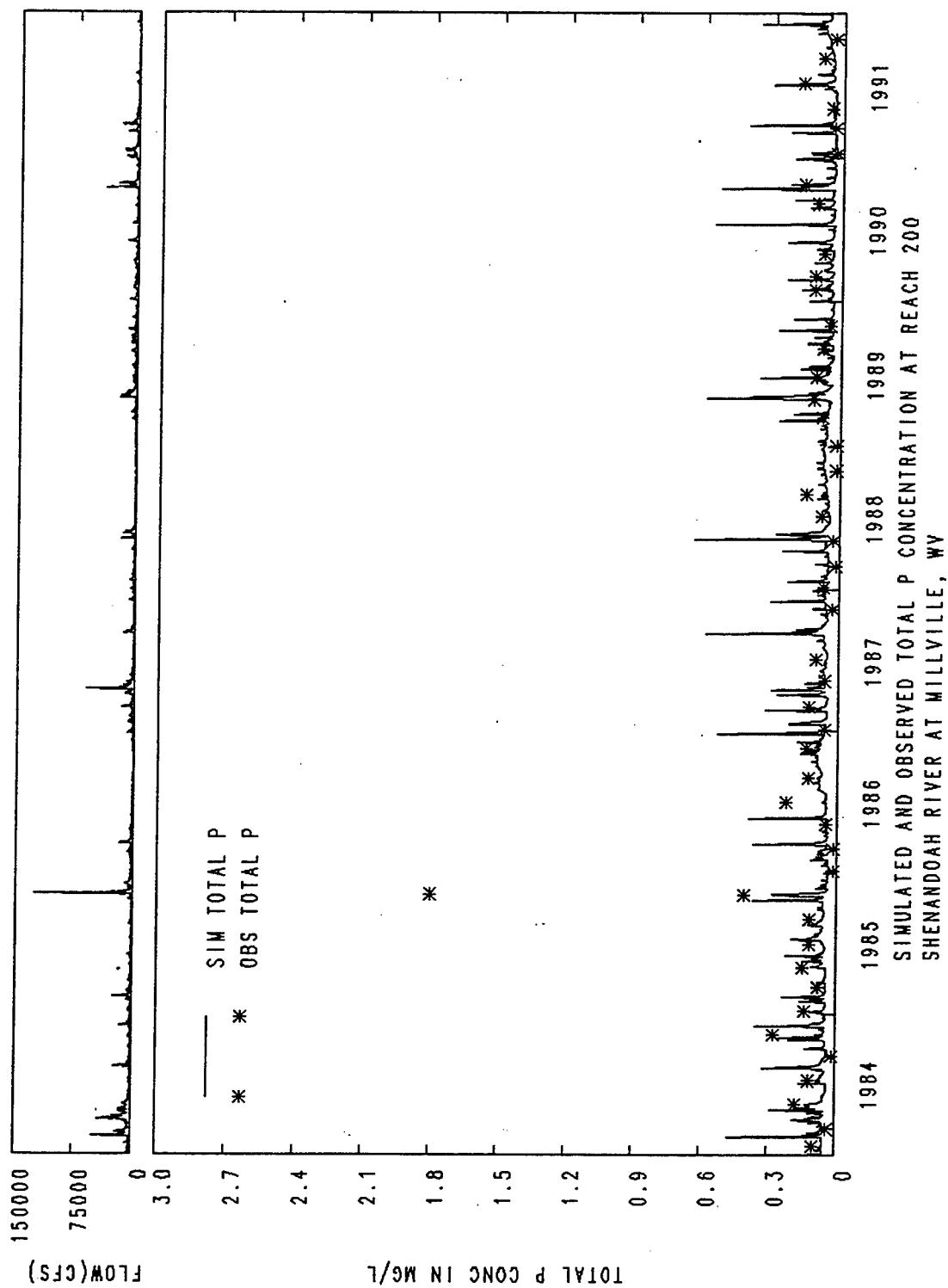


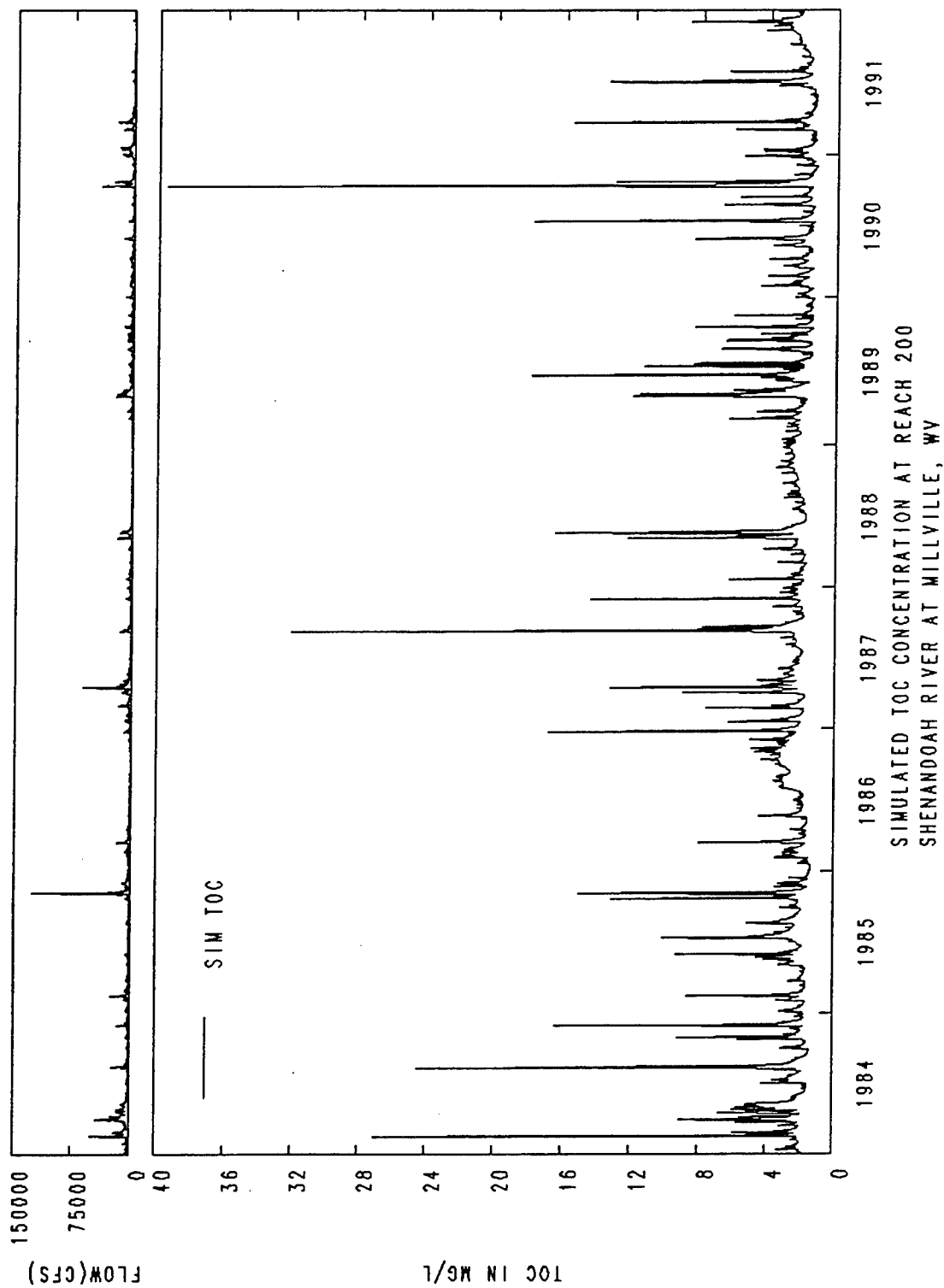


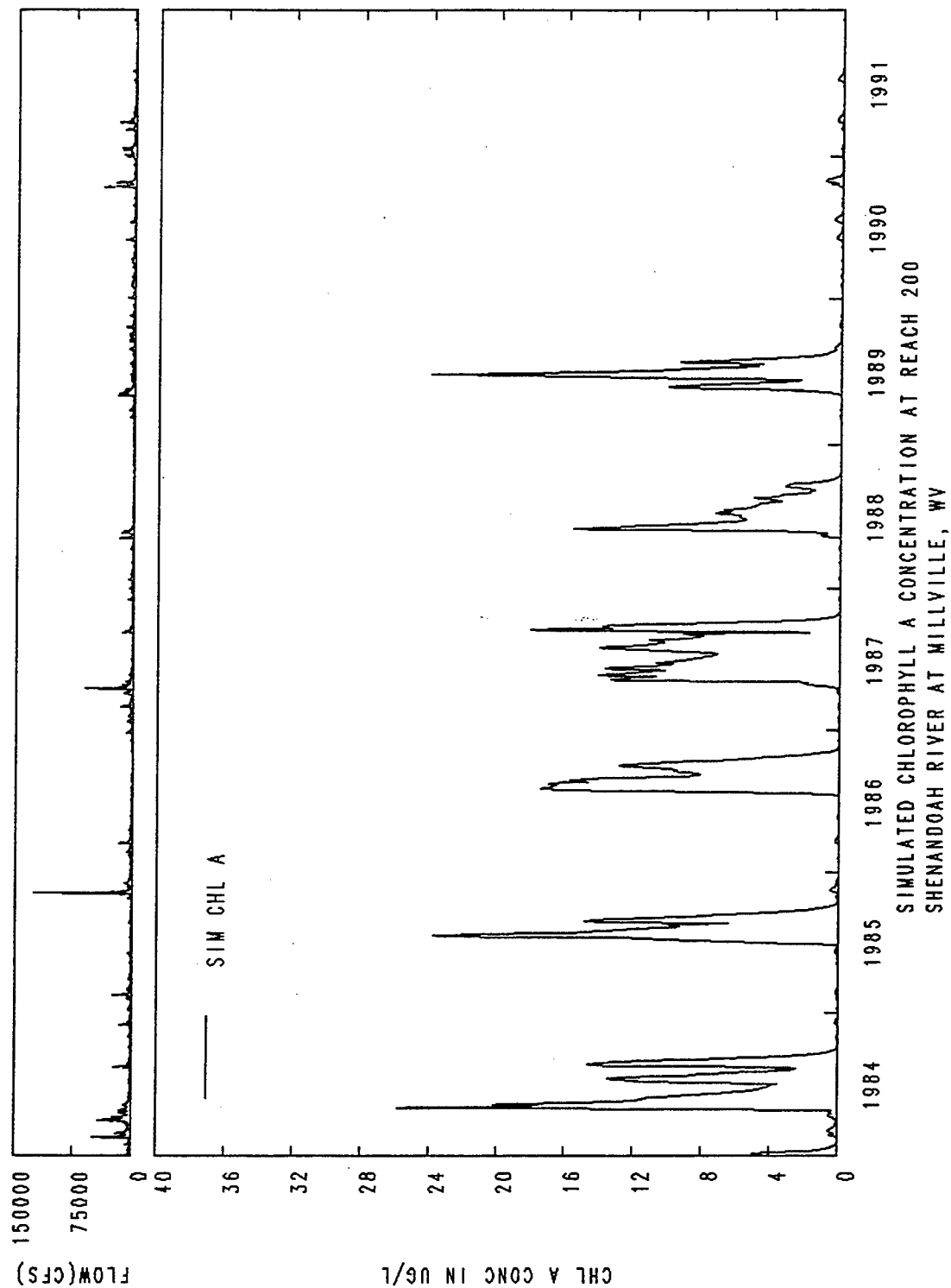


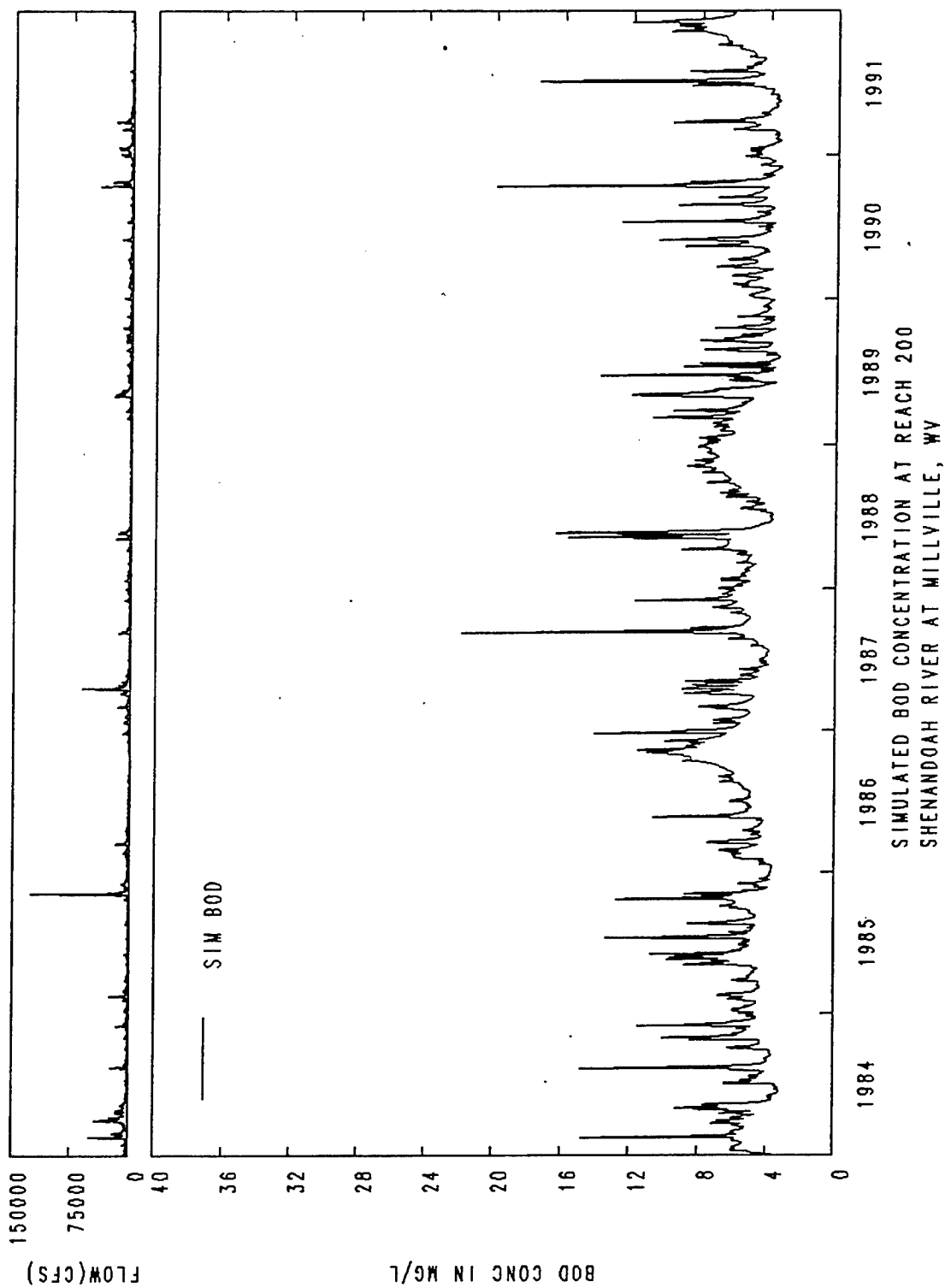


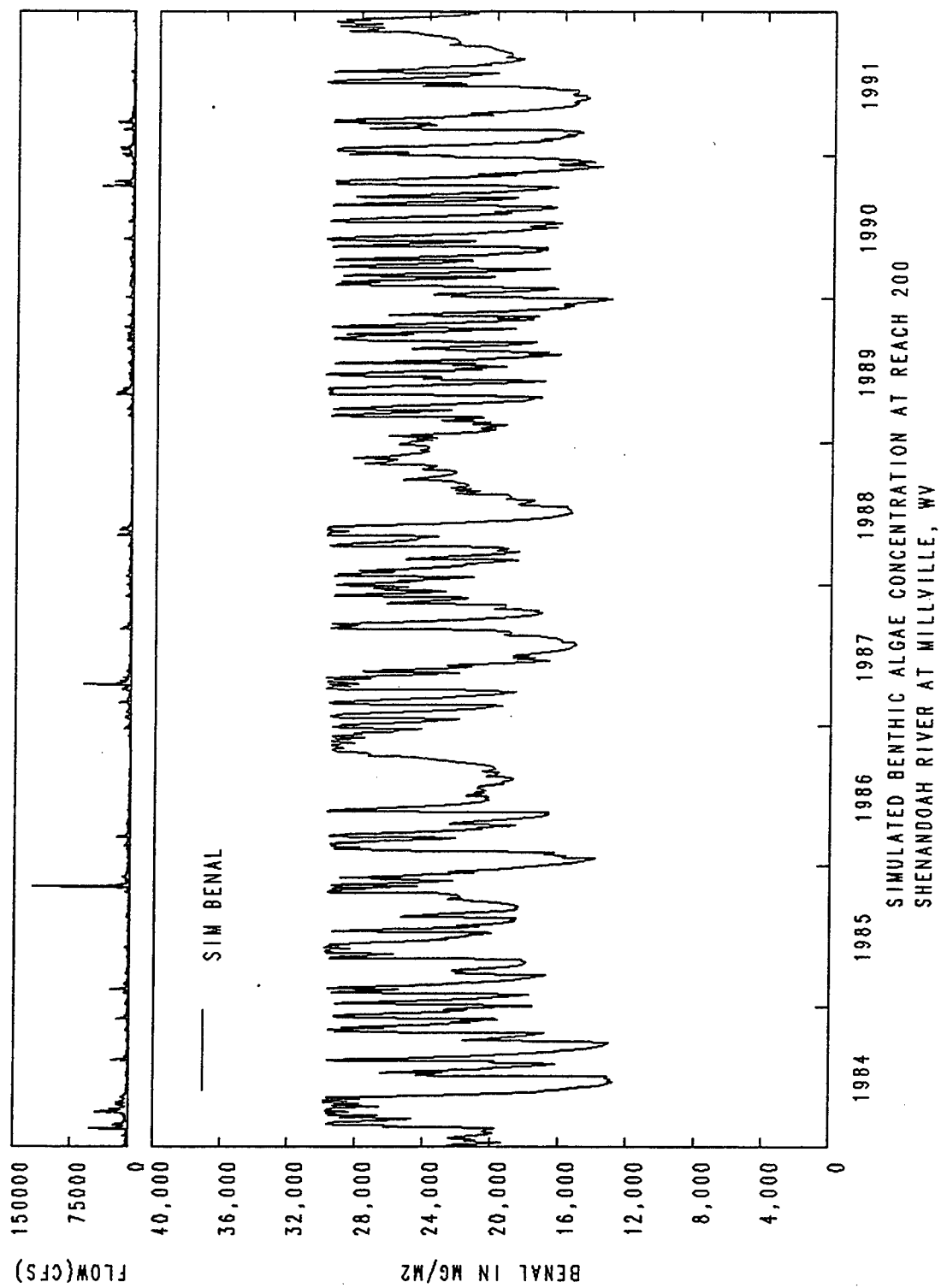












AGCHEM Summary for Shenandoah Basin (FOREST), PERLND 191

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	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	44.62	44.13	30.78	43.77	31.24	45.43	42.02	35.11	39.64
Runoff (in)									
Surface	1.493	1.132	0.1520	0.9600	0.1300	0.4660	0.8780	0.4090	0.7025
Interflow	6.703	5.959	1.154	4.212	0.9340	5.133	4.863	2.914	3.984
Baseflow	10.63	9.195	6.282	9.027	6.133	10.08	9.236	8.439	8.628
Total	18.83	16.29	7.588	14.20	7.197	15.68	14.98	11.76	13.31
Sediment Loss (t/a)	0.9664E-01	0.5773E-01	0.1761E-01	0.7754E-01	0.2538E-01	0.5561E-01	0.8091E-01	0.4070E-01	0.5652E-01
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.4050E-01	0.2027E-01	0.6206E-02	0.3715E-01	0.4644E-02	0.1735E-01	0.1628E-01	0.2161E-01	0.2050E-01
Interflow	0.8209	0.5604	0.4474	0.4974	0.1822	0.2860	0.4717	0.5296	0.4744
Baseflow	0.9103	0.3719	0.2609	0.7471	0.2497	0.4322	0.3600E-01	0.7047E-01	0.3848
Total	1.772	0.9525	0.7145	1.282	0.4365	0.7356	0.5240	0.6217	0.8799
NH3 Loss									
Surface	0.4035E-01	0.1580E-01	0.5003E-02	0.2221E-01	0.4662E-02	0.2965E-01	0.2375E-01	0.2194E-01	0.2042E-01
Interflow	0.6814E-01	0.4354E-01	0.2122E-01	0.3901E-01	0.1168E-01	0.2148E-01	0.3448E-01	0.3727E-01	0.3460E-01
Baseflow	0.2260E-01	0.2634E-01	0.2571E-01	0.2642E-01	0.2339E-01	0.2353E-01	0.1965E-01	0.1796E-01	0.2320E-01
Sediment	0.4039E-03	0.2194E-03	0.7699E-04	0.3632E-03	0.1334E-03	0.2442E-03	0.3367E-03	0.2005E-03	0.2473E-03
Total	0.1315	0.8590E-01	0.5202E-01	0.8801E-01	0.3987E-01	0.7490E-01	0.7823E-01	0.7738E-01	0.7848E-01
Labile ORGN									
Surface	0.5451E-01	0.4797E-01	0.7878E-02	0.3507E-01	0.4397E-02	0.3255E-01	0.3680E-01	0.2116E-01	0.3004E-01
Interflow	0.4111	0.3321	0.7677E-01	0.2287	0.6371E-01	0.2752	0.1563	0.2250	0.2250
Baseflow	0.2434	0.2378	0.2327	0.2275	0.2233	0.2176	0.2131	0.2087	0.2255
Sediment	0.7161E-01	0.4362E-01	0.1532E-01	0.6688E-01	0.2299E-01	0.4618E-01	0.7153E-01	0.3641E-01	0.4682E-01
Refrac ORGN									
Surface	0.2997E-01	0.2515E-01	0.3986E-02	0.1705E-01	0.2079E-02	0.1477E-01	0.1627E-01	0.9156E-02	0.1480E-01
Interflow	0.2262	0.1961	0.4680E-01	0.1478	0.4267E-01	0.1892	0.1777	0.1092	0.1420
Baseflow	0.1678	0.1680	0.1686	0.1692	0.1702	0.1703	0.1709	0.1714	0.1696
Sediment	0.2877	0.1676	0.5626E-01	0.2372	0.7970E-01	0.1537	0.2314	0.1152	0.1661
Total ORGN Loss	1.492	1.218	0.6083	1.130	0.6091	1.099	1.174	0.8276	1.020
Total N Loss (lb/a)	3.395	2.257	1.375	2.499	1.085	1.910	1.776	1.527	1.978
STORAGES (lb/ac)									
AG Plant N	538.1	571.4	605.9	632.7	651.7	663.1	676.8	689.3	628.6
Litter N	28.41	28.67	29.78	31.07	32.17	33.03	33.79	34.48	31.43
BG Plant N Storage									
Surface	20.15	20.40	20.61	20.83	20.98	21.21	21.40	21.55	20.89
Upper	212.6	225.3	236.3	246.0	250.7	254.6	258.0	260.2	243.0
Lower	69.37	82.66	90.89	96.16	97.80	98.10	96.59	94.60	90.77
Total AG, BG, Litter	868.6	928.5	983.5	1027.	1053.	1070.	1087.	1100.	1015.
Total Soil, Litter & Plant N Storage	6528.	6534.	6540.	6547.	6553.	6561.	6568.	6574.	6551.

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Atmos Dep(lb/ac) NH <sub>3</sub> -N NO <sub>3</sub> -N ORGN	2.245	2.070	1.775	2.204	1.852	2.618	2.130	1.833	2.091
	6.639	6.417	6.019	6.635	5.997	7.040	6.498	6.097	6.418
	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Plant Uptake Above Ground									
	NH <sub>3</sub> Uptake								
	NO <sub>3</sub> Uptake								
	ORGN								
Below Ground									
	NH <sub>3</sub> Uptake								
	NO <sub>3</sub> Uptake								
	ORGN								
Above Ground Plant N N to Litter									
Litter N Return to Labile ORGN									
	Surface								
	Upper								
	Total								
to Refrac ORGN									
	Surface								
	Upper								
	Total								
8G Plant N Ret to Labile ORGN									
	Surface								
	Upper								
	Lower								
to Refrac ORGN									
	Surface								
	Upper								
	Lower								
L/R ORGN Conversion									
LORGN Mineralization Denitrification									
	Surface								
	Upper								
	Lower								
NH <sub>3</sub> Immobilization									
	Surface								
	Upper								
	Lower								
NH <sub>3</sub> Immobilization									
	Surface								
	Upper								
	Lower								
NH <sub>3</sub> Immobilization									
	Surface								
	Upper								
	Lower								

AGCHEM Summary for Shenandoah Basin (HI-TILL), PERLND 192

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	44.62	44.13	30.78	43.77	31.24	45.43	42.02	35.11	39.64
Runoff (in)									
Surface	12.56	10.26	2.800	8.937	2.793	9.565	8.650	5.806	7.672
Interflow	3.814	4.083	1.632	3.321	1.314	3.968	3.360	2.276	2.971
Baseflow	6.730	5.448	4.297	5.500	4.057	6.378	5.551	4.979	5.367
Total	23.10	19.79	8.728	17.76	8.164	19.91	17.56	13.06	16.01
Sediment Loss (t/a)	1.680	1.160	0.2870	1.570	0.4290	0.8060	1.130	0.7720	0.9793
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.9428	0.3997	0.1873	0.4585	0.2552	0.9296	0.5557	0.4597	0.5236
Interflow	13.52	14.19	8.679	12.14	11.70	16.65	17.28	10.77	13.12
Baseflow	3.245	2.714	2.705	4.195	2.911	6.498	3.331	3.187	3.598
Total	17.71	17.31	11.57	16.80	14.86	24.08	21.17	14.42	17.24
NH3 Loss									
Surface	3.044	0.4876	0.5578	0.8832	0.3121	1.916	1.472	0.9163	1.199
Interflow	1.621	1.208	1.306	2.010	1.290	1.690	1.524	1.085	1.467
Baseflow	0.5637E-01	0.4850E-01	0.4020E-01	0.5453E-01	0.4181E-01	0.6421E-01	0.4504E-01	0.4289E-01	0.4919E-01
Sediment	0.1879E-01	0.1206E-01	0.3411E-02	0.1689E-01	0.5344E-02	0.9662E-02	0.1271E-01	0.9153E-02	0.1100E-01
Total	4.741	1.756	1.907	2.964	1.649	3.680	3.054	2.053	2.725
ORGN Sediment	5.649	3.961	0.9810	5.327	1.454	2.718	3.869	2.632	3.324
Total N Loss (lb/a)	28.10	23.02	14.46	25.09	17.97	30.48	28.09	19.10	23.29
P04 Loss									
Surface	0.8622	0.5242	0.3730	0.5280	0.3575	1.039	0.9892	0.4245	0.6372
Interflow	0.6191	1.261	0.6228	1.403	0.8863	1.676	1.176	0.7216	1.046
Baseflow	0.6276E-03	0.8009E-05	0.5108E-05	0.8517E-05	0.5254E-05	0.1443E-04	0.1009E-04	0.7291E-05	0.8579E-04
Sediment	0.7742E-01	0.6099E-01	0.1654E-01	0.8373E-01	0.2641E-01	0.4578E-01	0.6447E-01	0.4283E-01	0.5227E-01
Total	1.559	1.846	1.012	2.015	1.270	2.761	2.230	1.189	1.735
ORGP Sediment	1.571	1.109	0.2730	1.486	0.4052	0.7585	1.080	0.7335	0.9270
Total P Loss (lb/a)	3.130	2.956	1.285	3.501	1.675	3.520	3.310	1.922	2.662
Atm Depn. NO3 (lb/a)	6.639	6.417	6.019	6.635	5.997	7.040	6.498	6.097	6.418
Atm Depn. NH4 (lb/a)	2.245	2.070	1.775	2.204	1.852	2.618	2.130	1.833	2.091
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Ammonia appln. (lb/a)	125.2	128.7	126.0	129.0	126.4	129.0	126.4	119.8	126.3
Nitrate appln. (lb/a)	28.48	29.46	28.69	29.46	29.05	29.46	29.46	26.41	28.81
ORGN appln. (lb/a)	55.59	56.34	55.82	56.76	54.93	56.76	53.20	56.76	55.77
Total N appln. (lb/a)	209.3	214.5	210.5	215.2	210.4	215.2	209.1	203.0	210.9
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-P appln. (lb/a)	42.29	44.28	42.74	44.39	43.90	44.39	43.43	44.39	43.73
ORGP appln. (lb/a)	14.99	15.19	15.05	15.30	14.81	15.30	14.34	15.30	15.03
Total P appln. (lb/a)	57.28	59.46	57.79	59.69	58.70	59.69	57.77	59.69	58.76
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.9000E-02	0.1400E-01	0.4000E-02	0.7000E-02	0.7000E-02	0.2100E-01	0.1500E-01	0.1000E-01	0.1087E-01
Upper	74.06	73.75	79.19	83.48	73.51	73.79	74.91	67.22	74.99
Lower	52.37	57.02	57.03	57.02	57.02	57.01	57.01	57.01	56.44
Total	126.4	130.8	136.2	140.5	130.5	130.8	131.9	124.3	131.4

Phosphorus	0.8000E-02	0.1100E-01	0.3000E-02	0.6000E-02	0.6000E-02	0.1900E-01	0.1000E-01	0.7000E-02	0.8750E-02
Surface	19.57	19.96	19.99	19.95	19.97	19.90	20.03	18.96	19.79
Upper	3.753	3.752	3.752	3.752	3.753	3.752	3.752	3.752	3.752
Lower	23.33	23.73	23.74	23.71	23.73	23.67	23.79	22.72	23.55
Total									
Deficit (lb/a)									
Nitrogen	1.442	1.436	1.446	1.444	1.444	1.430	1.436	1.441	1.440
Surface	12.75	13.02	7.679	3.334	13.32	13.02	11.91	19.62	11.83
Upper	4.811	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6014
Lower	19.00	14.45	9.125	4.778	14.76	14.45	13.34	21.06	13.87
Total									
Phosphorus	1.243	1.239	1.248	1.245	1.245	1.232	1.240	1.243	1.242
Surface	0.4643	0.6320E-01	0.4349E-01	0.7360E-01	0.8092E-01	0.1501	0.2894E-01	1.059	0.2454
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	1.708	1.302	1.291	1.318	1.326	1.382	1.269	2.303	1.487
Total									
Other Fluxes-lb/ac									
N Mineralization	18.89	21.95	22.74	22.98	21.11	20.67	21.83	21.59	21.47
P Mineralization	2.378	2.444	2.393	2.343	2.340	2.421	2.489	2.351	2.395
Denitrification	3.365	4.879	5.833	6.319	6.458	9.057	5.662	5.361	5.867
N Immobilization	24.15	25.98	27.23	26.91	26.37	26.42	27.69	24.39	26.14
P Immobilization	13.72	21.38	17.39	20.69	21.24	22.94	20.71	20.54	19.83

AGCHEM Summary for Shenandoah Basin (LOW-TILL), PERLND 193

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	44.62	44.13	30.78	43.77	31.24	45.43	42.02	35.11	39.64
Runoff (in)									
Surface	10.75	8.789	1.977	7.365	1.764	7.414	7.168	4.787	6.252
Interflow	3.759	4.072	1.560	3.221	1.233	3.949	3.392	2.256	2.930
Baseflow	7.364	6.094	4.659	5.994	4.475	7.124	6.263	5.511	5.936
Total	21.87	18.95	8.197	16.58	7.471	18.49	16.82	12.55	15.12
Sediment Loss (t/a)	1.210	0.8640	0.1780	1.060	0.2750	0.5170	0.8110	0.4890	0.6755
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.7955	0.2866	0.1135	0.3534	0.1346	0.6497	0.4266	0.3716	0.3914
Interflow	11.80	13.06	7.570	10.74	10.33	16.33	17.64	10.18	12.21
Baseflow	2.798	1.881	1.309	2.103	1.983	4.889	1.727	1.658	2.293
Total	15.39	15.23	8.992	13.20	12.45	21.87	19.79	12.21	14.89
NH3 Loss									
Surface	3.722	0.4150	0.5573	0.8716	0.2458	1.557	1.450	0.7943	1.202
Interflow	1.221	0.7812	0.8635	1.417	1.164	1.196	1.146	0.7240	1.064
Baseflow	0.5897E-01	0.4888E-01	0.3887E-01	0.5401E-01	0.4181E-01	0.6441E-01	0.4456E-01	0.4184E-01	0.4917E-01
Sediment	0.1334E-01	0.8868E-02	0.2062E-02	0.1130E-01	0.3149E-02	0.5903E-02	0.8898E-02	0.5740E-02	0.7408E-02
Total	5.016	1.254	1.462	2.354	1.455	2.824	2.649	1.566	2.322
ORGN Sediment	5.048	3.657	0.7571	4.470	1.161	2.147	3.423	2.069	2.842
Total N Loss (lb/a)	25.46	20.14	11.21	20.02	15.07	26.84	25.86	15.84	20.06
PO4 Loss									
Surface	1.280	0.5173	0.3937	0.5815	0.4235	0.9270	0.9548	0.4690	0.6934
Interflow	0.5690	0.7288	0.3835	0.9190	0.7092	1.377	0.8115	0.4726	0.7463
Baseflow	0.6374E-03	0.6373E-05	0.2347E-05	0.2553E-05	0.1295E-05	0.3008E-05	0.1215E-05	0.8564E-06	0.8188E-04
Sediment	0.5560E-01	0.4479E-01	0.1029E-01	0.5585E-01	0.1690E-01	0.2905E-01	0.4477E-01	0.2740E-01	0.3558E-01
Total	1.906	1.291	0.7875	1.556	1.150	2.333	1.811	0.9690	1.475
ORGP Sediment	1.348	0.9852	0.2026	1.198	0.3108	0.5769	0.9194	0.5542	0.7619
Total P Loss (lb/a)	3.254	2.276	0.9901	2.755	1.460	2.910	2.730	1.523	2.237
Atm Depn. NO3 (lb/a)	6.639	6.417	6.019	6.635	5.997	7.040	6.498	6.097	6.418
Atm Depn. NH4 (lb/a)	2.245	2.070	1.775	2.204	1.852	2.618	2.130	1.833	2.091
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Ammonia appln. (lb/a)	127.5	131.6	128.5	131.7	129.6	131.7	128.9	121.4	128.9
Nitrate appln. (lb/a)	29.30	30.41	29.54	30.41	29.95	30.41	26.95	29.67	29.67
ORGN appln. (lb/a)	55.44	56.53	55.90	56.76	55.76	56.76	52.74	56.76	55.83
Total N appln. (lb/a)	212.2	218.5	214.0	218.9	215.4	218.9	212.0	205.1	214.4
Atm Depn. PO4 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
PO4-P appln. (lb/a)	41.32	43.63	41.88	43.69	43.42	43.69	42.60	43.69	42.99
ORGP appln. (lb/a)	14.94	15.24	15.07	15.30	15.30	15.30	14.22	15.30	15.05
Total P appln. (lb/a)	56.26	58.87	56.95	58.99	58.45	58.99	56.82	58.99	58.04
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.2600E-01	0.2300E-01	0.7000E-02	0.2000E-01	0.1300E-01	0.4400E-01	0.1900E-01	0.2100E-01	0.2162E-01
Upper	80.39	82.10	88.93	91.81	80.70	78.40	81.72	75.73	82.47
Lower	51.35	61.09	58.43	54.81	61.10	59.30	57.83	51.33	56.91
Total	131.8	143.2	147.4	146.6	141.8	137.7	139.6	127.1	139.4

Phosphorus	0.1700E-01	0.1700E-01	0.5000E-02	0.1500E-01	0.1000E-01	0.3500E-01	0.1300E-01	0.1500E-01	0.1587E-01
Surface	19.29	19.77	20.00	20.01	19.99	18.98	20.04	19.15	19.65
Upper	3.753	3.752	3.752	3.752	3.458	3.752	2.911	2.046	3.397
Lower	23.06	23.54	23.76	23.77	23.46	22.77	22.96	21.21	23.07
Total									
Deficit (lb/a)									
Nitrogen									
Surface	1.525	1.528	1.543	1.531	1.539	1.507	1.531	1.530	1.529
Upper	12.48	10.87	3.995	1.130	12.24	14.39	11.19	17.11	10.43
Lower	9.936	0.0000	2.672	6.271	0.0000	1.759	3.269	9.718	4.203
Total	23.94	12.39	8.211	8.931	13.78	17.65	15.99	28.36	16.16
Phosphorus									
Surface	1.234	1.234	1.246	1.235	1.241	1.216	1.237	1.236	1.235
Upper	0.7351	0.2510	0.1905E-01	0.2963E-01	0.4673E-01	1.035	0.1031E-01	0.8659	0.3741
Lower	0.0000	0.0000	0.0000	0.0000	0.2951	0.0000	0.8408	1.705	0.3551
Total	1.969	1.485	1.265	1.265	1.583	2.251	2.088	3.807	1.964
Other Fluxes-lb/ac									
N Mineralization	18.74	22.12	22.02	22.13	22.23	20.10	20.54	18.56	20.81
P Mineralization	2.696	2.749	2.712	2.690	2.504	2.736	2.610	2.112	2.601
Denitrification	2.392	2.950	2.192	2.607	3.802	6.039	2.455	2.124	3.070
N Immobilization	24.96	26.77	28.20	27.93	27.28	27.08	28.70	25.05	27.00
P Immobilization	15.90	22.75	18.83	22.02	21.66	23.11	21.57	21.46	20.91

AGCHEM Summary for Shenandoah Basin (PASTURE), PERLND 194

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	44.62	44.13	30.78	43.77	31.24	45.43	42.02	35.11	39.64
Runoff (in)									
Surface	10.50	8.556	1.619	6.678	1.230	7.397	7.056	4.138	5.896
Interflow	2.608	2.735	0.8530	2.174	0.6970	2.645	2.236	1.514	1.933
Baseflow	7.266	5.895	4.156	5.722	4.290	6.754	6.172	5.443	5.712
Total	20.37	17.19	6.628	14.57	6.217	16.80	15.46	11.10	13.54
Sediment Loss (t/a)	0.3050	0.1930	0.8909E-01	0.2070	0.6382E-01	0.2260	0.1970	0.1730	0.1817
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.5249	0.3167	0.6931E-01	0.3151	0.9114E-01	0.5370	0.3544	0.2651	0.3092
Interflow	0.8034	1.143	0.8633	1.032	0.4456	0.8419	1.228	0.9690	0.9158
Baseflow	3.448	2.643	2.217	3.623	2.670	4.181	3.195	2.946	3.115
Total	4.777	4.103	3.150	4.969	3.206	5.559	4.778	4.180	4.340
NH3 Loss									
Surface	0.7346	0.3341	0.1110	0.3596	0.9110E-01	0.5294	0.4203	0.3352	0.3644
Interflow	0.7462E-01	0.1333	0.5730E-01	0.1166	0.4474E-01	0.8005E-01	0.9371E-01	0.7718E-01	0.8469E-01
Baseflow	0.8316E-01	0.9195E-01	0.7209E-01	0.1123	0.8404E-01	0.1284	0.9118E-01	0.8319E-01	0.9329E-01
Sediment	0.3247E-02	0.1861E-02	0.8546E-03	0.2052E-02	0.6315E-03	0.2389E-02	0.1964E-02	0.1842E-02	0.1855E-02
Total	0.8957	0.5611	0.2412	0.5906	0.2205	0.7402	0.6071	0.4974	0.5442
ORGN Sediment	0.7818	0.4854	0.2258	0.5295	0.1548	0.5734	0.4977	0.4533	0.4627
Total N Loss (lb/a)	6.454	5.149	3.617	6.090	3.582	6.873	5.883	5.130	5.347
PO4 Loss									
Surface	0.1439	0.2257	0.1007	0.2210	0.5055E-01	0.2508	0.2829	0.2012	0.1846
Interflow	0.9153E-01	0.3129E-01	0.2610E-01	0.4913E-01	0.1408E-01	0.2177E-01	0.2820E-01	0.3423E-01	0.3704E-01
Baseflow	0.6477E-03	0.1504E-04	0.9235E-05	0.1643E-04	0.9474E-05	0.2491E-04	0.2154E-04	0.1550E-04	0.9498E-04
Sediment	0.1292E-01	0.9110E-02	0.4293E-02	0.9984E-02	0.2997E-02	0.1108E-01	0.9475E-02	0.8704E-02	0.8570E-02
Total	0.2490	0.2661	0.1311	0.2801	0.6764E-01	0.2837	0.3206	0.2442	0.2303
ORGP Sediment	0.2103	0.1321	0.6170E-01	0.1438	0.4175E-01	0.1552	0.1355	0.1230	0.1254
Total P Loss (lb/a)	0.4594	0.3982	0.1928	0.4239	0.1094	0.4388	0.4560	0.3672	0.3557
Atm Depn. NO3 (lb/a)	6.639	6.417	6.019	6.635	5.997	7.040	6.498	6.097	6.418
Atm Depn. NH4 (lb/a)	2.245	2.070	1.775	2.204	1.852	2.618	2.130	1.833	2.091
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Ammonia appln. (lb/a)	18.30	18.25	18.25	18.25	18.30	18.25	18.25	18.25	18.26
Nitrate appln. (lb/a)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORGN appln. (lb/a)	22.50	22.44	22.44	22.44	22.50	22.44	22.44	22.44	22.46
Total N appln. (lb/a)	40.80	40.69	40.69	40.69	40.80	40.69	40.69	40.69	40.72
Atm Depn. PO4 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
PO4-P appln. (lb/a)	12.28	12.25	12.25	12.25	12.28	12.25	12.25	12.25	12.25
ORGP appln. (lb/a)	12.28	12.25	12.25	12.25	12.28	12.25	12.25	12.25	12.25
Total P appln. (lb/a)	24.56	24.49	24.49	24.49	24.56	24.49	24.49	24.49	24.51
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.3000E-02	0.3000E-02	0.1000E-02	0.4000E-02	0.2000E-02	0.8000E-02	0.3000E-02	0.3000E-02	0.3375E-02
Upper	18.02	20.36	19.82	19.70	20.80	21.24	21.11	18.82	19.98
Lower	15.72	15.72	15.72	15.72	15.72	15.72	15.72	15.72	15.72
Total	33.74	36.08	35.54	35.42	36.52	36.96	36.83	34.54	35.70

Phosphorus	0.7000E-02	0.7000E-02	0.1000E-02	0.8000E-02	0.4000E-02	0.1700E-01	0.7000E-02	0.6000E-02	0.7125E-02
Surface	11.69	11.78	11.35	11.56	11.83	11.83	11.77	11.07	11.61
Upper	0.9010	0.9000	0.9000	0.9000	0.9010	0.9000	0.9000	0.9000	0.9003
Lower	12.60	12.69	12.25	12.47	12.73	12.75	12.67	11.97	12.52
Total									
Deficit (lb/a)									
Nitrogen	0.3971	0.3968	0.3996	0.3966	0.3981	0.3922	0.3968	0.3974	0.3968
Surface	5.918	3.570	4.117	4.239	3.144	2.703	2.824	5.118	3.954
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	6.315	3.966	4.516	4.635	3.542	3.095	3.220	5.515	4.351
Total									
Phosphorus	0.8934	0.8936	0.8992	0.8927	0.8962	0.8838	0.8936	0.8949	0.8934
Surface	4.532	4.429	4.857	4.648	4.390	4.386	4.464	5.146	4.606
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	5.425	5.323	5.757	5.541	5.286	5.270	5.358	6.041	5.500
Total									
Other Fluxes-lb/ac									
N Mineralization	24.13	24.94	24.29	24.25	24.80	25.18	25.39	24.20	24.65
P Mineralization	3.053	2.982	2.826	2.871	2.909	2.999	3.121	2.852	2.952
Denitrification	2.684	2.651	2.685	3.455	3.125	3.975	3.144	2.979	3.087
N Immobilization	6.229	6.970	7.088	7.106	7.099	7.321	7.576	6.916	7.038
P Immobilization	3.626	2.143	2.088	2.512	2.190	2.562	2.560	2.284	2.496

AGCHEM Summary for Shenandoah Basin (HAY), PERLND 196

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	44.62	44.13	30.78	43.77	31.24	45.43	42.02	35.11	39.64
Runoff (in)									
Surface	10.50	8.556	1.619	6.678	1.230	7.397	7.056	4.138	5.896
Interflow	2.608	2.735	0.830	2.174	0.6970	2.645	2.236	1.514	1.933
Baseflow	7.266	5.895	4.156	5.722	4.290	6.754	6.172	5.443	5.712
Total	20.37	17.19	6.628	14.57	6.217	16.80	15.46	11.10	13.54
Sediment Loss (t/a)	0.4690	0.3660	0.6165E-01	0.3770	0.4554E-01	0.2130	0.3460	0.1420	0.2525
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.5218	0.3204	0.7492E-01	0.3133	0.9238E-01	0.6367	0.3532	0.2827	0.3244
Interflow	1.208	0.8475	0.4567	0.9498	0.3422	0.9380	1.074	0.7305	0.8183
Baseflow	3.629	2.452	1.960	3.207	2.420	3.746	2.871	2.542	2.853
Total	5.359	3.620	2.492	4.470	2.855	5.321	4.299	3.556	3.997
NH3 Loss									
Surface	0.6435	0.2664	0.9241E-01	0.2809	0.7291E-01	0.8619	0.3223	0.3076	0.3560
Interflow	0.5971E-01	0.4920E-01	0.4356E-01	0.3292E-01	0.1517E-01	0.5795E-01	0.4688E-01	0.4247E-01	0.4348E-01
Baseflow	0.8300E-01	0.9167E-01	0.7188E-01	0.1120	0.8381E-01	0.1281	0.9092E-01	0.8294E-01	0.9304E-01
Sediment	0.4829E-02	0.3610E-02	0.6317E-03	0.3922E-02	0.4739E-03	0.2364E-02	0.3566E-02	0.1486E-02	0.2610E-02
Total	0.7910	0.4109	0.2085	0.4297	0.1724	1.050	0.4636	0.4345	0.4951
ORGN Sediment	1.279	0.9977	0.1668	1.037	0.1169	0.5567	0.9467	0.3653	0.6833
Total N Loss (lb/a)	7.429	5.028	2.867	5.937	3.144	6.928	5.709	4.355	5.175
P04 Loss									
Surface	0.3682	0.2653	0.1255	0.3348	0.6346E-01	0.5796	0.3527	0.4456	0.3169
Interflow	0.1581	0.6294E-01	0.2891E-01	0.1144	0.2027E-01	0.5512E-01	0.4911E-01	0.3470E-01	0.6544E-01
Baseflow	0.6427E-03	0.3427E-05	0.4741E-06	0.1425E-06	0.4311E-07	0.2988E-07	0.3333E-07	0.2334E-07	0.8086E-04
Sediment	0.2104E-01	0.1822E-01	0.3267E-02	0.2011E-01	0.2250E-02	0.1146E-01	0.1801E-01	0.7590E-02	0.1274E-01
Total	0.5480	0.3465	0.1577	0.4693	0.8598E-01	0.4462	0.4198	0.4878	0.3952
ORGP Sediment	0.3430	0.2753	0.4579E-01	0.2810	0.3129E-01	0.1527	0.2606	0.9915E-01	0.1861
Total P Loss (lb/a)	0.8910	0.6217	0.2035	0.7503	0.1173	0.7989	0.6804	0.5870	0.5813
Atm Depn. NO3 (lb/a)	6.639	6.417	6.019	6.635	5.997	7.040	6.498	6.097	6.418
Atm Depn. NH4 (lb/a)	2.245	2.070	1.775	2.204	1.852	2.618	2.130	1.833	2.091
Atm Depn. ORGN (lb/a)	0.5068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Ammonia appln. (lb/a)	28.20	28.20	28.22	28.31	27.81	27.56	28.22	27.52	28.01
Nitrate appln. (lb/a)	7.320	7.320	7.320	7.320	7.320	7.070	7.320	7.145	7.267
ORGN appln. (lb/a)	8.614	8.614	8.638	8.760	8.079	8.760	8.638	8.395	8.562
Total N appln. (lb/a)	44.14	44.14	44.18	44.39	43.21	43.39	44.18	43.06	43.84
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-p appln. (lb/a)	27.42	27.42	27.43	27.48	27.22	26.65	27.43	26.76	27.23
ORGP appln. (lb/a)	3.304	3.304	3.313	3.360	3.099	3.650	3.313	3.220	3.284
Total P appln. (lb/a)	30.73	30.73	30.75	30.84	30.32	30.01	30.75	29.98	30.51
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.4000E-02	0.4000E-02	0.1000E-02	0.5000E-02	0.3000E-02	0.1000E-02	0.4000E-02	0.4000E-02	0.4375E-02
Upper	32.93	33.99	33.52	32.68	33.96	33.09	33.76	33.62	33.44
Lower	12.84	12.84	12.84	12.84	12.84	12.84	12.84	12.84	12.84
Total	45.78	46.83	46.36	45.52	46.80	45.94	46.60	46.46	46.28

Phosphorus	0.8000E-02	0.7000E-02	0.1000E-02	0.8000E-02	0.5000E-02	0.1700E-01	0.7000E-02	0.6000E-02	0.7375E-02
Surface	15.97	15.97	15.98	15.97	15.96	15.71	16.00	16.00	15.94
Upper	3.002	3.001	2.350	1.027	0.6360	0.6010	0.5400	0.4830	1.455
Lower	18.98	18.98	18.33	17.00	16.60	16.32	16.55	16.49	17.41
Total									
Deficit (lb/a)									
Nitrogen									
Surface	0.4964	0.4959	0.4996	0.4957	0.4976	0.4902	0.4962	0.4964	0.4960
Upper	3.795	2.743	3.197	4.033	2.764	3.648	2.991	3.121	3.286
Lower	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	4.291	3.239	3.697	4.529	3.262	4.138	3.487	3.617	3.782
Phosphorus									
Surface	0.9931	0.9931	0.9992	0.9923	0.9959	0.9832	0.9931	0.9943	0.9930
Upper	0.6342E-01	0.4930E-01	0.3479E-01	0.5626E-01	0.6464E-01	0.3196	0.2048E-01	0.2253E-01	0.7888E-01
Lower	0.0000	0.0000	0.6512	1.975	2.367	2.401	2.462	2.519	1.547
Total	1.057	1.042	1.685	3.023	3.427	3.704	3.475	3.536	2.619
Other Fluxes-lb/ac									
N Mineralization	21.11	21.02	20.85	20.80	20.98	21.24	21.48	21.28	21.09
P Mineralization	2.288	2.294	1.906	1.605	1.516	1.476	1.577	1.380	1.755
Denitrification	4.354	3.530	3.729	4.637	4.346	4.997	4.167	4.020	4.222
N Immobilization	9.006	9.766	9.709	9.869	9.736	9.784	10.08	9.638	9.698
P Immobilization	14.30	12.86	11.11	12.55	12.28	12.36	11.78	10.04	12.16

AGCHEM Summary for Shenandoah Basin (FOREST), PERLND 201

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	40.44	37.80	28.30	37.69	28.36	38.09	40.03	28.53	34.91
Runoff (in)									
Surface	0.8040	0.2990	0.5200E-01	0.1140	0.3600E-01	0.1400	0.4860	0.2980	0.2786
Interflow	5.067	3.041	1.037	1.857	0.8340	1.998	3.077	1.886	2.350
Baseflow	9.441	7.593	5.745	6.691	5.431	6.880	7.925	6.385	7.011
Total	15.31	10.93	6.834	8.662	6.301	9.018	11.49	8.569	9.639
Sediment Loss (t/a)	0.8234E-01	0.4467E-01	0.3114E-01	0.1206E-01	0.1425E-01	0.1351E-01	0.1370	0.1521E-01	0.3867E-01
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.2376E-01	0.8967E-02	0.3524E-02	0.7505E-02	0.4691E-02	0.9904E-02	0.7091E-02	0.1409E-01	0.9942E-02
Interflow	0.7118	0.4395	0.6885	0.9605	0.1611	0.1397	0.3495	0.3733	0.4780
Baseflow	0.8489	0.3550	0.2953	1.972	0.3307	0.4802	0.6137E-01	0.9071E-01	0.5543
Total	1.584	0.8035	0.9873	2.940	0.4965	0.6298	0.4179	0.4781	1.042
NH3 Loss									
Surface	0.2922E-01	0.6293E-02	0.2958E-02	0.4192E-02	0.3740E-02	0.1430E-01	0.1622E-01	0.6824E-02	0.1047E-01
Interflow	0.5707E-01	0.3198E-01	0.1824E-01	0.2925E-01	0.8975E-02	0.1174E-01	0.2305E-01	0.2349E-01	0.2547E-01
Baseflow	0.1931E-01	0.2292E-01	0.2028E-01	0.2534E-01	0.2032E-01	0.2178E-01	0.1746E-01	0.1573E-01	0.2039E-01
Sediment	0.3548E-03	0.1698E-03	0.9782E-05	0.4509E-04	0.0000	0.6346E-04	0.6168E-03	0.6502E-04	0.1656E-03
Total	0.1060	0.6135E-01	0.4148E-01	0.5883E-01	0.3303E-01	0.4788E-01	0.5734E-01	0.4611E-01	0.5650E-01
Labile ORGN									
Surface	0.3633E-01	0.1854E-01	0.4510E-02	0.8579E-02	0.3289E-02	0.1070E-01	0.2140E-01	0.1611E-01	0.1493E-01
Interflow	0.3186	0.1828	0.6896E-01	0.1163	0.5410E-01	0.1180	0.1631	0.9451E-01	0.1395
Baseflow	0.2108	0.2060	0.2017	0.1973	0.1937	0.1888	0.1850	0.1811	0.1955
Sediment	0.6382E-01	0.3499E-01	0.1793E-02	0.9338E-02	0.0000	0.1038E-01	0.1343	0.1150E-01	0.3327E-01
Refrac ORGN									
Surface	0.1970E-01	0.9634E-02	0.2298E-02	0.4173E-02	0.1545E-02	0.4808E-02	0.9196E-02	0.6816E-02	0.7271E-02
Interflow	0.1757	0.1089	0.4221E-01	0.7785E-01	0.3755E-01	0.8527E-01	0.1194	0.6924E-01	0.8952E-01
Baseflow	0.1453	0.1454	0.1460	0.1465	0.1474	0.1475	0.1480	0.1485	0.1468
Sediment	0.2534	0.1330	0.6740E-02	0.3343E-01	0.0000	0.3422E-01	0.4231	0.3563E-01	0.1149
Total ORGN Loss	1.224	0.8392	0.4742	0.5935	0.4376	0.5996	1.203	0.5634	0.7418
Total N Loss (lb/a)	2.914	1.704	1.503	3.592	0.9671	1.277	1.679	1.088	1.841
STORAGES (lb/ac)									
AG Plant N	540.1	576.0	613.2	642.7	663.4	676.0	688.7	703.3	637.9
Litter N	28.47	28.80	30.07	31.48	32.69	33.63	34.40	35.15	31.84
BG Plant N Storage									
Surface	20.15	20.38	20.55	20.71	20.90	21.14	21.28	21.43	20.82
Upper	213.2	227.0	234.8	244.3	249.0	252.4	254.7	255.7	241.4
Lower	69.33	82.73	91.55	100.4	101.7	102.2	100.4	97.86	93.27
Total AG, BG, Litter	871.3	934.8	990.2	1039.	1068.	1085.	1099.	1113.	1025.
Total Soil, Litter & Plant N Storage	6528.	6534.	6540.	6545.	6551.	6559.	6565.	6571.	6549.

## NH4-N SOLN STORAGE

Surface	0.0000	0.0000	0.0000	0.0000	0.0000	0.3000E-02	0.0000	0.0000	0.3750E-03
Upper	0.4800E-01	0.3200E-01	0.6400E-01	0.3600E-01	0.4400E-01	0.2900E-01	0.3600E-01	0.5500E-01	0.4300E-01
Interflow	0.0000	0.0000	0.0000	0.0000	0.0000	0.1000E-02	0.2000E-02	0.0000	0.3750E-03
Lower	0.9100E-01	0.7100E-01	0.6600E-01	0.5300E-01	0.5000E-01	0.3600E-01	0.3300E-01	0.3500E-01	0.5437E-01
GW	0.5000E-02	0.4000E-02	0.9000E-02	0.7000E-02	0.4000E-02	0.4000E-02	0.4000E-02	0.7000E-02	0.5500E-02
Total	0.1440	0.1070	0.1400	0.9600E-01	0.9700E-01	0.7300E-01	0.7500E-01	0.9700E-01	0.1036
NH4-N ADS STORAGE									
Surface	0.2830	0.2880	0.2640	0.2690	0.3470	0.2700	0.2650	0.2620	0.2810
Upper	7.717	7.491	7.883	7.521	8.465	7.395	7.432	7.861	7.721
Lower	6.366	6.271	6.322	6.239	6.311	6.145	6.128	6.198	6.247
GW	5.101	5.038	5.491	5.222	5.409	5.096	5.047	5.464	5.234
Total	19.47	19.09	19.96	19.25	20.53	18.91	18.87	19.78	19.48

## NO3/2-N STORAGE

Surface	0.2300E-01	0.7300E-01	0.8000E-01	0.3100E-01	0.8200E-01	0.0000	0.1200E-01	0.2500E-01	0.4075E-01
Upper	1.243	0.3900	4.387	0.5770	1.415	0.3920	0.5980	1.835	1.355
Interflow	0.1000E-02	0.0000	0.3100E-01	0.6000E-02	0.0000	0.1000E-01	0.3600E-01	0.1500E-01	0.1237E-01
Lower	1.382	0.6880	7.423	0.6130	0.6510	0.1170	0.2470	1.557	1.582
GW	0.6300E-01	0.2700E-01	0.5460	0.1330	0.1100	0.2500E-01	0.2100E-01	0.1690	0.1368
Total	2.712	1.158	12.47	1.359	2.258	0.5440	0.9140	3.600	3.126

## Labile ORGN(SOLN)

Surface	0.1100E-01	0.1200E-01	0.1200E-01	0.1200E-01	0.1300E-01	0.1300E-01	0.1300E-01	0.1400E-01	0.1250E-01
Upper	0.1160	0.1090	0.9000E-01	0.9400E-01	0.9000E-01	0.8900E-01	0.8800E-01	0.8500E-01	0.9625E-01
Interflow	0.0000	0.0000	0.1000E-02	0.1000E-02	0.0000	0.3000E-02	0.6000E-02	0.1000E-02	0.1500E-02
Lower	0.5600E-01	0.4700E-01	0.4100E-01	0.3600E-01	0.3200E-01	0.2900E-01	0.2600E-01	0.2400E-01	0.3637E-01
GW	0.4400E-01	0.4300E-01	0.4200E-01	0.4100E-01	0.4000E-01	0.3900E-01	0.3800E-01	0.3700E-01	0.4050E-01
Total	0.2260	0.2110	0.1940	0.1840	0.1740	0.1730	0.1720	0.1610	0.1869
Labile ORGN(ADS)									
Surface	51.37	51.84	53.90	55.92	57.70	58.34	60.01	62.57	56.46
Upper	520.6	491.4	444.8	421.2	403.9	402.5	396.6	383.7	433.1
Lower	250.2	212.3	183.0	161.0	143.3	129.5	118.2	108.6	163.3
GW	196.2	192.3	187.6	184.1	179.9	176.2	172.6	168.5	182.2
Total	1018.	947.9	869.3	822.3	784.8	766.6	747.5	723.4	835.0

## Refrac ORGN(SOLN)

Surface	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02	0.6000E-02
Upper	0.6700E-01	0.6700E-01	0.6700E-01	0.6800E-01	0.6800E-01	0.6800E-01	0.6800E-01	0.6900E-01	0.6775E-01
Interflow	0.0000	0.0000	0.0000	0.1000E-02	0.0000	0.2000E-02	0.4000E-02	0.1000E-02	0.1000E-02
Lower	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01	0.3700E-01
GW	0.3000E-01	0.3100E-01	0.3100E-01	0.3100E-01	0.3100E-01	0.3100E-01	0.3100E-01	0.3100E-01	0.3088E-01
Total	0.1400	0.1400	0.1410	0.1420	0.1420	0.1440	0.1460	0.1430	0.1423
Refrac ORGN(ADS)									
Surface	197.7	195.5	194.0	192.5	190.8	189.0	187.1	185.7	191.5
Upper	2208.	2216.	2226.	2234.	2241.	2247.	2254.	2261.	2236.
Lower	1206.	1212.	1217.	1221.	1225.	1229.	1233.	1236.	1222.
GW	1004.	1008.	1011.	1015.	1018.	1021.	1025.	1028.	1016.
Total	4616.	4631.	4648.	4662.	4675.	4687.	4698.	4710.	4666.

FLUXES (lb/ac)									
Atmos Dep(lb/ac)									
NH3-N	2.118	1.894	1.670	1.964	1.684	2.303	2.051	1.537	1.903
NO3-N	6.464	6.154	5.854	6.257	5.703	6.603	6.329	5.688	6.131
ORGN	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Plant Uptake									
Above Ground									
NH3 Uptake	49.74	46.73	44.95	38.20	34.73	29.03	31.17	32.91	38.43
NO3 Uptake	8.564	8.456	12.97	13.01	8.447	6.559	4.832	5.535	8.547
Below Ground									
NH3 Uptake	48.91	47.93	43.42	39.13	35.64	29.78	32.54	33.44	38.85
NO3 Uptake	11.95	12.33	17.76	18.28	11.12	8.875	6.764	7.904	11.87
Above Ground Plant N to Litter									
	18.17	19.36	20.71	21.74	22.47	22.91	23.33	23.82	21.56
Litter N Return to Labile ORGN									
Surface	5.956	5.753	5.878	6.143	6.427	6.642	6.820	6.973	6.324
Upper	12.76	12.33	12.60	13.16	13.77	14.23	14.61	14.94	13.55
Total	18.72	18.08	18.47	19.31	20.20	20.87	21.43	21.92	19.87
to Refrac ORGN									
Surface	0.3135	0.3028	0.3094	0.3233	0.3382	0.3496	0.3590	0.3670	0.3328
Upper	0.6717	0.6488	0.6629	0.6928	0.7248	0.7490	0.7692	0.7865	0.7132
Total	0.9851	0.9516	0.9723	1.016	1.063	1.099	1.128	1.154	1.046
BG Plant N Ret to Labile ORGN									
Surface	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Upper	18.37	20.59	29.99	23.54	24.38	18.58	22.79	26.86	23.14
Lower	8.397	10.64	12.10	13.51	14.08	14.19	14.03	13.73	12.58
Total	26.77	31.24	42.09	37.04	38.47	32.77	36.82	40.59	35.72
to Refrac ORGN									
Surface	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Upper	0.9669	1.084	1.578	1.239	1.283	0.9777	1.199	1.413	1.218
Lower	0.4420	0.5601	0.6369	0.7109	0.7411	0.7469	0.7383	0.7227	0.6624
Total	1.409	1.644	2.215	1.950	2.025	1.725	1.938	2.136	1.880
L/R ORGN Conversion									
	14.33	13.61	14.75	12.04	11.26	9.517	9.711	10.19	11.93
LORGN Mineralization									
Denitrification	120.2	113.3	130.5	98.45	90.57	68.37	73.47	81.43	97.04
NH3 Nitrification	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NH3 Immobilization	18.95	17.07	39.80	20.37	17.55	10.07	8.205	12.75	18.10
NO3 Immobilization	4.434	3.825	3.106	3.411	3.022	3.404	3.583	2.888	3.459
NO3 Immobilization	3.199	3.192	2.629	3.506	2.293	2.319	2.150	1.833	2.640

AGCHEM Summary for Shenandoah Basin (HI-TILL), PERLND 202

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	40.44	37.80	28.30	37.69	28.36	38.09	40.03	28.53	34.91
Runoff (in)									
Surface	9.659	5.334	2.054	5.115	2.742	5.333	6.257	2.940	4.929
Interflow	3.514	3.112	1.464	2.698	1.412	2.627	2.944	1.438	2.401
Baseflow	6.200	5.025	4.629	4.629	3.652	4.772	5.248	4.146	4.743
Total	19.37	13.47	7.790	12.44	7.806	12.73	14.45	8.525	12.07
Sediment Loss (t/a)	1.920	0.6400	0.2150	0.5980	0.3800	0.7150	1.200	0.4890	0.7696
Nutrient Loss (lb/a)									
N03 Loss									
Surface	0.7305	0.2387	0.3119	0.3204	0.2394	0.4338	0.3434	0.2295	0.3560
Interflow	11.35	9.195	7.216	9.849	11.60	14.07	12.23	6.181	10.21
Baseflow	2.973	2.120	1.910	2.870	2.332	4.426	2.428	1.891	2.619
Total	15.05	11.55	9.438	13.04	14.17	18.93	15.01	8.301	13.19
NH3 Loss									
Surface	1.872	0.2809	0.8822	0.7709	0.4079	0.8172	1.052	0.5405	0.8280
Interflow	1.197	1.004	1.251	1.356	1.266	1.289	1.055	0.6030	1.128
Baseflow	0.5040E-01	0.4219E-01	0.3574E-01	0.4498E-01	0.3691E-01	0.5039E-01	0.4483E-01	0.3344E-01	0.4236E-01
Sediment	0.2195E-01	0.6534E-02	0.2537E-02	0.6619E-02	0.4527E-02	0.9085E-02	0.1348E-01	0.5864E-02	0.8837E-02
Total	3.142	1.334	2.172	2.178	1.715	2.165	2.166	1.183	2.007
ORGN Sediment	6.451	2.167	0.7226	1.998	1.278	2.421	4.053	1.652	2.593
Total N Loss (lb/a)	24.65	15.05	12.33	17.21	17.16	23.52	21.22	11.14	17.79
P04 Loss									
Surface	0.4757	0.3451	0.4886	0.3811	0.4319	0.7458	0.7329	0.2799	0.4851
Interflow	0.4450	0.9954	0.5440	1.050	0.9696	1.306	0.8298	0.4098	0.8187
Baseflow	0.5401E-03	0.1574E-05	0.1298E-05	0.2407E-05	0.1541E-05	0.1990E-05	0.1166E-05	0.8796E-06	0.6887E-04
Sediment	0.9416E-01	0.3375E-01	0.1223E-01	0.3282E-01	0.2350E-01	0.4111E-01	0.6789E-01	0.2704E-01	0.4156E-01
Total	1.015	1.374	1.045	1.464	1.425	2.093	1.631	0.7168	1.345
ORGP Sediment	1.802	0.6079	0.2013	0.5592	0.3584	0.6768	1.138	0.4615	0.7256
Total P Loss (lb/a)	2.817	1.982	1.246	2.023	1.783	2.770	2.769	1.178	2.071
Atm Depn. N03 (lb/a)	6.464	6.154	5.854	6.257	5.703	6.603	6.329	5.688	6.131
Atm Depn. NH4 (lb/a)	2.118	1.894	1.670	1.964	1.684	2.303	2.051	1.537	1.903
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6069	0.6069
Ammonia appln. (lb/a)	122.9	123.0	124.0	124.2	123.2	105.9	121.5	118.5	120.4
Nitrate appln. (lb/a)	27.08	27.42	27.42	27.42	27.42	21.48	27.13	25.53	26.36
ORGN appln. (lb/a)	51.32	49.80	51.24	51.47	50.01	50.82	48.63	51.47	50.59
Total N appln. (lb/a)	201.3	200.2	202.7	203.1	200.6	178.2	197.3	195.5	197.4
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-P appln. (lb/a)	42.70	42.98	43.37	43.43	43.03	43.16	42.21	43.43	43.04
ORGP appln. (lb/a)	11.04	10.67	11.06	11.12	10.72	10.94	10.83	11.12	10.94
Total P appln. (lb/a)	53.74	53.65	54.42	54.55	53.76	54.11	53.04	54.55	53.98
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.1600E-01	0.9000E-02	0.6000E-02	0.1100E-01	0.1200E-01	0.1200E-01	0.1900E-01	0.4000E-02	0.1113E-01
Upper	74.56	76.53	81.09	80.95	67.85	60.75	71.97	75.12	73.60
Lower	52.77	57.04	57.05	57.02	57.01	55.79	57.01	56.20	56.24
Total	127.3	133.6	138.1	138.0	124.9	116.5	129.0	131.3	129.8

Phosphorus	0.1400E-01	0.8000E-02	0.6000E-02	0.1000E-01	0.1000E-01	0.1100E-01	0.1300E-01	0.4000E-02	0.9500E-02
Surface	21.48	22.38	22.09	22.37	22.30	22.44	22.41	22.41	22.23
Upper	1.892	2.770	2.932	4.045	4.202	2.799	2.108	2.108	3.119
Lower	23.39	25.16	25.03	26.42	26.51	25.25	24.52	24.52	25.36
Total									
Deficit (lb/a)									
Nitrogen									
Surface	1.435	1.441	1.445	1.439	1.438	1.432	1.447	1.439	1.439
Upper	12.28	10.28	5.794	18.94	26.03	14.86	11.73	13.23	13.23
Lower	4.446	0.0000	0.0000	0.0000	1.220	0.0000	0.8493	0.8144	0.8144
Total	18.16	11.72	7.239	20.38	28.69	16.30	14.02	15.49	15.49
Phosphorus									
Surface	1.387	1.392	1.394	1.391	1.390	1.387	1.397	1.391	1.391
Upper	0.9487	0.6620E-01	0.3416	0.8305E-01	0.1401	0.2516E-01	0.2454E-01	0.2117	0.2117
Lower	2.312	1.433	1.270	0.1583	0.0000	1.403	2.094	1.084	1.084
Total	4.647	2.892	3.006	1.632	1.530	2.815	3.515	2.686	2.686
Other Fluxes-lb/ac									
N Mineralization	19.75	22.45	22.99	22.05	18.53	21.48	22.11	21.62	21.62
P Mineralization	1.793	2.151	2.031	2.139	2.384	2.053	1.764	2.079	2.079
Denitrification	3.423	4.170	3.913	5.586	7.186	4.644	3.810	4.812	4.812
N Immobilization	24.28	25.38	26.65	25.82	21.63	26.91	24.42	25.20	25.20
P Immobilization	12.50	18.54	14.51	15.93	21.21	18.36	15.44	17.09	17.09

AGCHEM Summary for Shenandoah Basin (LOW-TILL), PERLND 203

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	40.44	37.80	28.30	37.69	28.36	38.09	40.03	28.53	34.91
Runoff (in)									
Surface	8.087	4.178	1.394	3.571	1.771	3.803	5.019	2.398	3.778
Interflow	3.423	3.057	1.407	2.525	1.382	2.470	2.910	1.357	2.316
Baseflow	6.673	5.470	4.534	4.996	4.102	5.121	5.668	4.378	5.118
Total	18.18	12.70	7.335	11.09	7.256	11.40	13.60	8.132	11.21
Sediment Loss (t/a)	1.180	0.4290	0.1160	0.3040	0.1340	0.3700	0.7010	0.2960	0.4413
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.8037	0.1674	0.2586	0.2261	0.1614	0.3267	0.3522	0.1840	0.3100
Interflow	9.466	8.941	6.206	7.669	10.42	13.50	13.16	4.901	9.283
Baseflow	2.517	1.289	0.8821	1.818	1.543	2.866	1.838	0.9351	1.711
Total	12.79	10.40	7.347	9.713	12.13	16.69	15.35	6.020	11.30
NH3 Loss									
Surface	1.795	0.2364	0.7105	0.7078	0.3195	0.7367	1.278	0.4520	0.7795
Interflow	0.8343	0.6118	0.8364	0.8760	1.215	1.019	0.7023	0.3512	0.8058
Baseflow	0.5220E-01	0.4219E-01	0.3450E-01	0.4513E-01	0.3763E-01	0.4963E-01	0.4397E-01	0.3222E-01	0.4218E-01
Sediment	0.1333E-01	0.4271E-02	0.1388E-02	0.3276E-02	0.1486E-02	0.4586E-02	0.7805E-02	0.3661E-02	0.4975E-02
Total	2.695	0.8946	1.583	1.632	1.574	1.810	2.032	0.8391	1.632
ORGN Sediment	4.966	1.788	0.4807	1.263	0.5479	1.537	2.969	1.247	1.850
Total N Loss (lb/a)	20.45	13.08	9.410	12.61	14.25	20.03	20.35	8.107	14.79
P04 Loss									
Surface	0.5982	0.3742	0.3735	0.4571	0.4974	0.8681	0.7773	0.2624	0.5260
Interflow	0.3842	0.6124	0.3720	0.6614	0.8669	1.102	0.5762	0.2481	0.6029
Baseflow	0.5433E-03	0.9215E-06	0.6555E-06	0.1278E-05	0.1081E-05	0.1486E-05	0.7181E-06	0.4499E-06	0.6874E-04
Sediment	0.5709E-01	0.2208E-01	0.6570E-02	0.1627E-01	0.8119E-02	0.2117E-01	0.3919E-01	0.1642E-01	0.2336E-01
Total	1.040	1.009	0.7521	1.135	1.372	1.992	1.393	0.5270	1.153
ORGP Sediment	1.328	0.4809	0.1290	0.3377	0.1472	0.4119	0.7967	0.3332	0.4956
Total P Loss (lb/a)	2.368	1.490	0.8811	1.473	1.519	2.404	2.189	0.8601	1.648
Atm Depn. NO3 (lb/a)	6.464	6.154	5.854	6.257	5.703	6.603	6.329	5.688	6.131
Atm Depn. NH4 (lb/a)	2.118	1.894	1.670	1.964	1.684	2.303	2.051	1.537	1.903
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6069	0.6069
Ammonia appln. (lb/a)	124.4	124.8	125.8	125.9	125.4	104.9	122.9	119.8	121.7
Nitrate appln. (lb/a)	28.96	29.39	29.39	29.39	29.39	22.48	29.02	27.34	28.17
ORGN appln. (lb/a)	54.20	52.89	54.41	54.54	53.73	54.18	51.68	54.54	53.77
Total N appln. (lb/a)	207.6	207.1	209.6	209.9	208.5	181.6	203.5	201.6	203.7
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-P appln. (lb/a)	42.27	42.68	43.09	43.12	42.90	42.92	41.70	43.12	42.72
ORGP appln. (lb/a)	14.61	14.26	14.67	14.70	14.48	14.60	13.93	14.70	14.49
Total P appln. (lb/a)	56.88	56.93	57.75	57.82	57.39	57.52	55.62	57.82	57.22
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.3000E-01	0.1900E-01	0.8000E-02	0.2500E-01	0.1700E-01	0.2000E-01	0.2400E-01	0.6000E-01	0.1862E-01
Upper	82.08	84.79	93.02	91.78	80.15	62.97	76.82	88.70	82.54
Lower	51.96	58.52	49.25	55.39	57.47	49.04	60.35	46.28	53.53
Total	134.1	143.3	142.3	147.2	137.6	112.0	137.2	135.0	136.1

Phosphorus	0.2500E-01	0.1600E-01	0.7000E-02	0.2100E-01	0.1400E-01	0.1700E-01	0.1700E-01	0.5000E-02	0.1525E-01
Surface	21.43	22.08	22.42	22.40	22.39	22.44	22.42	22.42	22.03
Upper	1.863	2.113	1.826	3.079	2.935	1.993	1.284	1.284	2.335
Lower	23.31	24.21	24.25	25.50	25.34	24.45	23.71	23.71	24.38
Total									
Deficit (lb/a)									
Nitrogen									
Surface	1.521	1.532	1.543	1.526	1.535	1.531	1.527	1.545	1.533
Upper	10.79	8.177	0.4533E-01	1.152	12.62	29.80	16.08	4.195	10.36
Lower	9.407	2.550	11.71	5.691	3.604	11.97	0.7649	14.71	7.551
Total	21.71	12.26	13.30	8.369	17.76	43.30	18.37	20.45	19.44
Phosphorus									
Surface	1.376	1.385	1.394	1.380	1.387	1.384	1.384	1.396	1.386
Upper	1.011	0.3467	0.1541E-01	0.2138E-01	0.4886E-01	1.799	0.2876E-02	0.1532E-01	0.4076
Lower	2.340	2.089	2.376	1.123	1.269	0.6181	2.209	2.918	1.868
Total	4.728	3.820	3.785	2.524	2.705	3.801	3.596	4.329	3.661
Other Fluxes-lb/ac									
N Mineralization	19.23	21.77	19.85	22.94	21.34	16.96	21.06	18.93	20.26
P Mineralization	2.061	2.323	2.185	2.390	2.233	2.440	2.203	1.861	2.212
Denitrification	2.387	2.064	1.048	3.027	2.570	3.974	2.997	1.189	2.407
N Immobilization	25.19	25.95	27.62	27.35	26.40	21.34	27.77	24.91	25.82
P Immobilization	15.23	20.09	16.44	21.60	16.93	21.78	19.75	16.47	18.54

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	40.44	37.80	28.30	37.69	28.36	38.09	40.03	28.53	34.91
Runoff (in)									
Surface	7.652	3.974	1.084	2.810	1.128	3.073	4.706	2.035	3.308
Interflow	2.474	2.006	0.7850	1.592	0.7930	1.632	1.996	0.9540	1.529
Baseflow	6.560	5.106	4.140	4.582	3.879	4.735	5.486	4.397	4.861
Total	16.69	11.09	6.009	8.984	5.800	9.439	12.19	7.386	9.697
Sediment Loss (t/a)	0.2740	0.1310	0.8290E-01	0.1510	0.5304E-01	0.1630	0.2150	0.5238E-01	0.1403
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.3999	0.1606	0.8201E-01	0.1391	0.8053E-01	0.2406	0.1932	0.1249	0.1776
Interflow	0.7075	0.7240	0.7047	0.6129	0.2799	0.4028	0.7853	0.5770	0.5993
Baseflow	3.034	2.051	1.998	2.747	2.286	2.898	2.813	2.206	2.504
Total	4.141	2.935	2.784	3.499	2.647	3.541	3.792	2.908	3.281
NH3 Loss									
Surface	0.4639	0.1798	0.9467E-01	0.1774	0.1030	0.2580	0.2904	0.1527	0.2150
Interflow	0.5398E-01	0.9249E-01	0.4152E-01	0.7150E-01	0.3902E-01	0.4956E-01	0.6331E-01	0.4020E-01	0.5645E-01
Baseflow	0.7356E-01	0.7791E-01	0.6658E-01	0.9188E-01	0.7672E-01	0.9942E-01	0.9006E-01	0.6531E-01	0.8018E-01
Sediment	0.2883E-02	0.1189E-02	0.7960E-03	0.1497E-02	0.4944E-03	0.1705E-02	0.2200E-02	0.5083E-03	0.1409E-02
Total	0.5943	0.3514	0.2036	0.3423	0.2192	0.4087	0.4460	0.2588	0.3530
ORGN Sediment	0.7169	0.3188	0.2107	0.3904	0.1242	0.4197	0.5628	0.1240	0.3584
Total N Loss (lb/a)	5.452	3.605	3.199	4.231	2.990	4.370	4.800	3.291	3.992
P04 Loss									
Surface	0.8642E-01	0.1239	0.6568E-01	0.1083	0.5055E-01	0.1099	0.1793	0.9813E-01	0.1028
Interflow	0.8279E-01	0.1960E-01	0.2115E-01	0.3161E-01	0.8256E-02	0.1165E-01	0.1520E-01	0.1731E-01	0.2595E-01
Baseflow	0.5457E-03	0.1553E-05	0.1624E-05	0.3608E-05	0.3068E-05	0.7094E-05	0.9894E-05	0.6137E-05	0.7233E-04
Sediment	0.1182E-01	0.5921E-02	0.3984E-02	0.7355E-02	0.2371E-02	0.7950E-02	0.1059E-01	0.2384E-02	0.6547E-02
Total	0.1816	0.1494	0.9081E-01	0.1473	0.6118E-01	0.1295	0.2051	0.1178	0.1353
ORGP Sediment	0.1927	0.8649E-01	0.5729E-01	0.1057	0.3336E-01	0.1133	0.1524	0.3331E-01	0.9682E-01
Total P Loss (lb/a)	0.3743	0.2359	0.1481	0.2530	0.9454E-01	0.2428	0.3575	0.1511	0.2322
Atm Depn. NO3 (lb/a)	6.464	6.154	5.854	6.257	5.703	6.603	6.329	5.688	6.131
Atm Depn. NH4 (lb/a)	2.118	1.894	1.670	1.964	1.684	2.303	2.051	1.537	1.903
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6069	0.6069
Ammonia appln. (lb/a)	13.72	13.68	13.68	13.68	13.72	13.68	13.68	13.68	13.69
Nitrate appln. (lb/a)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORGN appln. (lb/a)	16.83	16.78	16.78	16.78	16.83	16.78	16.78	16.80	16.80
Total N appln. (lb/a)	30.55	30.47	30.47	30.47	30.55	30.47	30.47	30.47	30.49
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-p appln. (lb/a)	9.179	9.154	9.154	9.154	9.179	9.154	9.154	9.154	9.160
ORGP appln. (lb/a)	9.179	9.154	9.154	9.154	9.179	9.154	9.154	9.154	9.160
Total P appln. (lb/a)	18.36	18.31	18.31	18.31	18.36	18.31	18.31	18.31	18.32
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.6000E-02	0.3000E-02	0.0000	0.4000E-02	0.4000E-02	0.5000E-02	0.5000E-02	0.1000E-02	0.3500E-02
Upper	15.96	17.57	15.85	17.28	17.56	18.84	18.31	16.16	17.19
Lower	15.72	15.72	15.72	15.72	15.72	15.72	15.72	15.72	15.72
Total	31.68	33.29	31.56	33.00	33.28	34.57	34.03	31.88	32.91

Phosphorus	0.1200E-01	0.4000E-02	0.1000E-02	0.8000E-02	0.7000E-02	0.9000E-02	0.7000E-02	0.1000E-02	0.6125E-02
Surface	9.408	9.289	8.392	9.409	9.101	9.563	9.377	8.674	9.152
Upper	0.7510	0.7500	0.7500	0.7500	0.7510	0.7500	0.7500	0.7500	0.7502
Lower	10.17	10.04	9.143	10.17	9.858	10.32	10.13	9.425	9.908
Total									
Deficit (lb/a)									
Nitrogen	0.3945	0.3977	0.3997	0.3957	0.3959	0.3953	0.3956	0.3997	0.3968
Surface	7.980	6.364	8.084	6.656	6.382	5.087	5.622	7.767	6.743
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	8.375	6.762	8.484	7.052	6.778	5.482	6.018	8.167	7.140
Total									
Phosphorus	0.7389	0.7459	0.7495	0.7424	0.7433	0.7418	0.7435	0.7493	0.7443
Surface	4.108	4.220	5.118	4.099	4.416	3.951	4.148	4.838	4.362
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	4.847	4.966	5.867	4.841	5.159	4.693	4.892	5.587	5.106
Total									
Other Fluxes-lb/ac									
N Mineralization	23.77	23.99	23.25	23.70	24.56	24.49	24.37	23.34	23.93
P Mineralization	2.996	2.931	2.752	2.881	2.878	2.994	3.017	2.738	2.898
Denitrification	2.608	2.296	2.460	3.122	2.953	3.487	3.085	2.609	2.828
N Immobilization	5.000	5.624	5.597	5.745	5.843	6.003	6.102	5.467	5.673
P Immobilization	2.894	1.210	1.425	1.798	1.388	1.664	1.651	1.480	1.689

AGCHEM Summary for Shenandoah Basin (HAY), PERLND 206

	1984	1985	1986	1987	1988	1989	1990	1991	SUM/AVER
Rainfall (in)	40.44	37.80	28.30	37.69	28.36	38.09	40.03	28.53	34.91
Runoff (in)									
Surface	7.652	3.974	1.084	2.810	1.128	3.073	4.706	2.035	3.308
Interflow	2.474	2.006	0.7850	1.592	0.7930	1.632	1.996	0.9540	1.529
Baseflow	6.560	5.106	4.140	4.582	3.879	4.735	5.486	4.397	4.861
Total	16.69	11.09	6.009	8.984	5.800	9.439	12.19	7.386	9.697
Sediment Loss (t/a)	0.2750	0.1020	0.1933E-01	0.5118E-01	0.1575E-01	0.6008E-01	0.1770	0.6325E-01	0.9545E-01
Nutrient Loss (lb/a)									
NO3 Loss									
Surface	0.4023	0.1584	0.8789E-01	0.1403	0.8073E-01	0.2841	0.1874	0.1372	0.1848
Interflow	1.227	0.4126	0.5027	0.7946	0.2788	0.6300	0.7567	0.6163	0.6523
Baseflow	3.239	2.024	1.787	2.430	2.170	2.875	2.763	2.056	2.418
Total	4.868	2.595	2.377	3.365	2.530	3.789	3.707	2.809	3.255
NH3 Loss									
Surface	0.4599	0.1255	0.1200	0.1427	0.8568E-01	0.2860	0.2167	0.1837	0.2025
Interflow	0.4754E-01	0.3056E-01	0.5104E-01	0.3109E-01	0.1901E-01	0.3608E-01	0.3173E-01	0.2465E-01	0.3396E-01
Baseflow	0.7346E-01	0.7771E-01	0.6640E-01	0.9168E-01	0.7656E-01	0.9926E-01	0.8986E-01	0.6513E-01	0.8001E-01
Sediment	0.2839E-02	0.9356E-03	0.1753E-03	0.4414E-03	0.1257E-03	0.6154E-03	0.1806E-02	0.6836E-03	0.9528E-03
Total	0.5837	0.2348	0.2376	0.2659	0.1814	0.4219	0.3401	0.2742	0.3174
ORGN Sediment	0.7443	0.2600	0.4512E-01	0.1189	0.3104E-01	0.1452	0.4807	0.1638	0.2486
Total N Loss (lb/a)	6.196	3.090	2.660	3.750	2.742	4.356	4.528	3.247	3.821
P04 Loss									
Surface	0.2648	0.1096	0.1385	0.1736	0.6628E-01	0.3099	0.3420	0.2419	0.2058
Interflow	0.1444	0.4603E-01	0.3683E-01	0.1094	0.2234E-01	0.4411E-01	0.3787E-01	0.2750E-01	0.5856E-01
Baseflow	0.5452E-03	0.3105E-07	0.5453E-07	0.1526E-06	0.5012E-07	0.2896E-07	0.2512E-07	0.3144E-07	0.6820E-04
Sediment	0.1271E-01	0.4725E-02	0.9223E-03	0.2260E-02	0.5908E-03	0.3146E-02	0.9188E-02	0.3450E-02	0.4624E-02
Total	0.4225	0.1603	0.1762	0.2853	0.8921E-01	0.3572	0.3891	0.2729	0.2691
ORGP Sediment	0.2003	0.7135E-01	0.1226E-01	0.3195E-01	0.8318E-02	0.3947E-01	0.1314	0.4375E-01	0.6735E-01
Total P Loss (lb/a)	0.6228	0.2317	0.1885	0.3173	0.9753E-01	0.3967	0.5204	0.3166	0.3364
Atm Depn. NO3 (lb/a)	6.464	6.154	5.854	6.257	5.703	6.603	6.329	5.688	6.131
Atm Depn. NH4 (lb/a)	2.118	1.894	1.670	1.964	1.684	2.303	2.051	1.537	1.903
Atm Depn. ORGN (lb/a)	0.6068	0.6070	0.6070	0.6070	0.6068	0.6070	0.6070	0.6070	0.6069
Ammonia appln. (lb/a)	28.29	28.20	28.26	28.31	27.92	27.10	27.41	27.63	27.89
Nitrate appln. (lb/a)	7.320	7.320	7.320	7.320	7.320	7.153	7.076	7.145	7.247
ORGN appln. (lb/a)	8.728	8.614	8.690	8.760	8.225	7.787	8.526	8.543	8.484
Total N appln. (lb/a)	44.33	44.14	44.27	44.39	43.47	42.04	43.01	43.32	43.62
Atm Depn. P04 (lb/a)	0.1427	0.1431	0.1431	0.1431	0.1427	0.1431	0.1431	0.1431	0.1430
P04-P appln. (lb/a)	27.47	27.42	27.45	27.48	27.27	26.56	26.59	26.82	27.13
ORGP appln. (lb/a)	3.348	3.304	3.333	3.360	3.155	2.987	3.270	3.277	3.254
Total P appln. (lb/a)	30.81	30.73	30.79	30.84	30.43	29.54	29.86	30.10	30.39
Plant Uptake (lb/a)									
Nitrogen									
Surface	0.8000E-02	0.3000E-02	0.1000E-02	0.6000E-02	0.5000E-02	0.6000E-02	0.6000E-02	0.1000E-02	0.4500E-02
Upper	33.24	35.39	34.48	33.03	33.88	33.78	33.77	33.20	33.84
Lower	12.84	12.84	12.84	12.84	12.84	12.84	12.84	12.84	12.84
Total	46.09	48.23	47.31	45.87	46.72	46.62	46.61	46.03	46.68

Phosphorus	0.1400E-01	0.6000E-02	0.1000E-02	0.9000E-02	0.9000E-02	0.1000E-01	0.9000E-02	0.2000E-02	0.7500E-02
Surface	15.98	15.97	15.99	15.98	15.97	15.94	16.02	16.00	15.98
Upper	1.368	0.6020	0.5910	1.144	0.6700	0.6060	0.5240	0.4560	0.7451
Lower	17.36	16.58	16.59	17.13	16.65	16.56	16.55	16.46	16.74
Total									
Deficit (lb/a)									
Nitrogen	0.4927	0.4970	0.4996	0.4945	0.4949	0.4942	0.4943	0.4995	0.4958
Surface	3.492	1.351	2.241	3.691	2.847	2.960	2.976	3.552	2.889
Upper	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lower	3.984	1.848	2.740	4.186	3.342	3.454	3.470	4.052	3.384
Total									
Phosphorus	0.9871	0.9945	0.9993	0.9914	0.9914	0.9902	0.9917	0.9989	0.9931
Surface	0.4370E-01	0.4475E-01	0.2617E-01	0.4069E-01	0.5735E-01	0.8310E-01	0.1550E-01	0.1730E-01	0.4107E-01
Upper	1.635	2.399	2.411	1.857	2.332	2.396	2.478	2.546	2.257
Lower	2.665	3.438	3.436	2.890	3.381	3.469	3.485	3.562	3.291
Total									
Other Fluxes-lb/ac									
N Mineralization	21.34	21.48	21.13	21.08	21.89	21.62	21.55	21.08	21.40
P Mineralization	1.751	1.700	1.517	1.659	1.532	1.536	1.543	1.312	1.569
Denitrification	4.331	3.469	3.515	4.317	4.437	5.242	4.483	4.016	4.226
N Immobilization	9.208	9.935	9.702	9.913	10.04	9.897	9.887	9.627	9.776
P Immobilization	14.12	12.48	10.10	14.08	11.60	12.94	11.24	9.298	11.98

PER ACRE LOAD CONTRIBUTED FROM EACH LAND USE IN SHENANDOAH BASIN (LB/AC); SEDIMENT IN TONS/AC

Segment 190

	-----Pervious-----					-----Impervious-----			Total
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Load
<b>NH3</b>									
1984	0.132	4.741	5.016	0.896	0.521	0.791	268.145	2.320	2.204
1985	0.086	1.756	1.254	0.561	0.372	0.411	264.176	2.090	1.607
1986	0.052	1.907	1.462	0.241	0.129	0.209	145.689	1.800	1.454
1987	0.088	2.964	2.354	0.591	0.394	0.430	255.534	2.260	1.837
1988	0.040	1.649	1.455	0.221	0.114	0.172	156.103	1.880	1.590
1989	0.075	3.680	2.824	0.740	0.329	1.050	256.157	2.700	1.713
1990	0.078	3.054	2.649	0.607	0.372	0.464	235.429	2.220	1.575
1991	0.077	2.053	1.566	0.497	0.231	0.435	190.798	1.890	1.374
MEAN	0.078	2.726	2.323	0.544	0.308	0.495	221.504	2.145	1.669
<b>NH3</b>									
1984	1.772	17.710	15.390	4.777	7.940	5.359	67.036	6.670	5.316
1985	0.953	17.310	15.230	4.103	6.690	3.620	66.044	5.960	4.420
1986	0.715	11.570	8.992	3.150	3.490	2.492	36.422	5.740	3.247
1987	1.282	16.800	13.200	4.969	6.240	4.470	63.883	6.560	4.743
1988	0.437	14.860	12.450	3.206	3.430	2.855	39.026	5.590	3.412
1989	0.736	24.080	21.870	5.559	6.940	5.321	64.039	7.340	5.362
1990	0.524	21.170	19.790	4.778	6.490	4.299	58.857	6.570	4.741
1991	0.622	14.420	12.210	4.180	5.080	3.556	47.700	5.900	3.909
MEAN	0.880	17.240	14.892	4.340	5.788	3.997	55.376	6.291	4.394
<b>ORGN</b>									
1984	1.492	5.649	5.048	2.143	3.569	1.279	2011.084	3.395	3.035
1985	1.218	3.961	3.657	1.394	2.445	0.998	1981.320	3.061	2.478
1986	0.608	0.981	0.757	0.652	0.675	0.167	1092.665	3.235	1.196
1987	1.129	5.327	4.470	1.476	2.675	1.037	1916.503	3.335	2.531
1988	0.609	1.454	1.161	0.482	0.549	0.117	1170.770	3.150	1.235
1989	1.100	2.718	2.147	1.620	2.033	0.557	1921.181	3.558	2.279
1990	1.174	3.869	3.423	1.414	2.452	0.947	1765.716	3.376	2.372
1991	0.828	2.632	2.069	1.244	1.380	0.365	1430.987	3.231	1.778
MEAN	1.020	3.324	2.842	1.303	1.972	0.683	1661.278	3.293	2.113
<b>TN</b>									
1984	3.395	28.100	25.460	7.816	12.030	7.429	1944.048	12.385	10.392
1985	2.257	23.020	20.140	6.058	9.507	5.028	1915.276	11.111	8.343
1986	1.375	14.460	11.210	4.044	4.294	2.867	1056.243	10.775	5.808
1987	2.499	25.090	20.020	7.035	9.309	5.937	1852.619	12.155	8.955
1988	1.085	17.970	15.070	3.909	4.093	3.144	1131.745	10.620	6.141
1989	1.910	30.480	26.840	7.919	9.302	6.928	1857.141	13.598	9.198
1990	1.776	28.090	25.860	6.799	9.314	5.709	1706.858	12.166	8.545
1991	1.527	19.100	15.840	5.921	6.691	4.355	1383.287	11.021	6.944
MEAN	1.978	23.289	20.055	6.188	8.068	5.175	1605.902	11.729	8.041
<b>PO4</b>									
1984	0.036	1.559	1.906	0.249	0.472	0.548	67.036	0.445	0.687
1985	0.021	1.846	1.291	0.266	0.321	0.347	66.044	0.396	0.593
1986	0.006	1.012	0.788	0.131	0.079	0.158	36.422	0.418	0.430
1987	0.033	2.015	1.556	0.280	0.353	0.469	63.883	0.434	0.654
1988	0.008	1.270	1.150	0.068	0.061	0.086	39.026	0.406	0.427
1989	0.026	2.761	2.333	0.284	0.261	0.646	64.039	0.469	0.568
1990	0.026	2.230	1.811	0.321	0.321	0.420	58.857	0.442	0.513
1991	0.018	1.189	0.969	0.244	0.173	0.488	47.700	0.419	0.429
MEAN	0.022	1.735	1.475	0.230	0.255	0.395	55.376	0.429	0.538
<b>ORGP</b>									
1984	0.036	1.571	1.348	0.405	0.510	0.343	100.554	0.485	0.401
1985	0.028	1.109	0.985	0.262	0.349	0.275	99.066	0.437	0.311
1986	0.014	0.273	0.203	0.123	0.096	0.046	54.633	0.462	0.146
1987	0.029	1.486	1.198	0.279	0.382	0.281	95.825	0.476	0.340
1988	0.015	0.405	0.311	0.088	0.078	0.031	58.539	0.450	0.158
1989	0.026	0.759	0.577	0.305	0.290	0.153	96.059	0.508	0.253
1990	0.030	1.080	0.919	0.266	0.350	0.261	88.286	0.482	0.285
1991	0.020	0.734	0.554	0.236	0.197	0.099	71.549	0.462	0.211
MEAN	0.025	0.927	0.762	0.245	0.282	0.186	83.064	0.470	0.263

## Segment 190

Segment	-----Pervious----->>-----Impervious----->							Total	
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Load
TP									
1984	0.071	3.130	3.254	0.654	0.982	0.891	335.181	0.930	1.156
1985	0.049	2.956	2.276	0.528	0.670	0.622	330.220	0.833	0.971
1986	0.020	1.285	0.990	0.254	0.176	0.204	182.111	0.880	0.613
1987	0.061	3.501	2.755	0.559	0.735	0.750	319.417	0.910	1.058
1988	0.023	1.675	1.460	0.156	0.139	0.117	195.128	0.856	0.625
1989	0.052	3.520	2.910	0.588	0.551	0.799	320.197	0.977	0.887
1990	0.056	3.310	2.730	0.587	0.671	0.680	294.286	0.924	0.857
1991	0.039	1.922	1.523	0.480	0.370	0.587	238.498	0.881	0.689
MEAN	0.046	2.662	2.237	0.476	0.537	0.581	276.880	0.899	0.857
BOD									
1984	14.795	123.300	74.700	11.010	28.860	25.200	4692.528	27.450	25.313
1985	12.537	116.100	72.300	7.350	19.770	20.490	4623.079	24.750	21.486
1986	6.305	20.520	11.730	3.450	5.460	3.810	2549.551	26.160	8.551
1987	10.579	141.300	80.700	7.650	21.630	21.000	4471.839	26.970	22.137
1988	5.959	32.100	23.490	2.646	4.440	3.120	2731.798	25.470	9.315
1989	10.832	75.000	45.900	8.460	16.440	12.690	4482.755	28.770	17.875
1990	10.940	113.700	68.400	7.410	19.830	19.350	4120.003	27.300	20.567
1991	8.009	69.900	36.000	6.390	11.160	8.280	3338.969	26.130	13.978
MEAN	9.995	86.490	51.653	6.796	15.949	14.243	3876.315	26.625	17.403
SED									
1984	0.097	1.680	1.210	0.305	0.291	0.469	0.000	0.000	0.291
1985	0.058	1.160	0.864	0.193	0.189	0.366	0.000	0.000	0.198
1986	0.018	0.287	0.178	0.089	0.043	0.062	0.000	0.000	0.054
1987	0.078	1.570	1.060	0.207	0.215	0.377	0.000	0.000	0.233
1988	0.025	0.429	0.275	0.064	0.032	0.046	0.000	0.000	0.058
1989	0.056	0.806	0.517	0.226	0.149	0.213	0.000	0.000	0.157
1990	0.081	1.130	0.811	0.197	0.193	0.346	0.000	0.000	0.205
1991	0.041	0.772	0.489	0.173	0.100	0.142	0.000	0.000	0.124
MEAN	0.057	0.979	0.676	0.182	0.152	0.253	0.000	0.000	0.165

## Segment 200

	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Total Load
-----Pervious----->>-----Impervious----->									
NH3									
1984	0.106	3.142	2.695	0.594	0.366	0.584	234.778	2.170	1.636
1985	0.061	1.334	0.895	0.351	0.214	0.235	211.834	1.910	1.405
1986	0.041	2.172	1.583	0.204	0.133	0.238	129.661	1.680	1.320
1987	0.059	2.178	1.632	0.342	0.214	0.266	214.257	2.020	1.418
1988	0.033	1.715	1.574	0.219	0.121	0.181	139.478	1.700	1.366
1989	0.048	2.165	1.810	0.409	0.232	0.422	194.622	2.390	0.970
1990	0.057	2.166	2.032	0.446	0.294	0.340	223.523	2.140	0.992
1991	0.046	1.183	0.839	0.259	0.120	0.274	134.624	1.580	0.847
MEAN	0.057	2.007	1.632	0.353	0.212	0.317	185.347	1.949	1.244
NO3									
1984	1.584	15.050	12.790	4.141	6.790	4.868	58.694	6.380	4.411
1985	0.804	11.550	10.400	2.935	5.080	2.595	52.959	5.700	3.188
1986	0.987	9.438	7.347	2.784	3.390	2.377	32.415	5.490	2.948
1987	2.940	13.040	9.713	3.499	4.440	3.365	53.564	6.140	4.513
1988	0.497	14.170	12.130	2.647	3.210	2.530	34.870	5.180	2.965
1989	0.630	18.930	16.690	3.541	4.690	3.789	48.656	6.780	3.788
1990	0.418	15.010	15.350	3.792	5.590	3.707	55.881	6.450	3.618
1991	0.478	8.301	6.020	2.908	3.590	2.809	33.656	5.390	2.683
MEAN	1.042	13.186	11.305	3.281	4.598	3.255	46.337	5.939	3.514
ORGN									
1984	1.224	6.451	4.966	2.004	2.360	0.744	1760.834	3.317	2.337
1985	0.839	2.167	1.788	0.983	1.254	0.260	1588.758	3.072	1.491
1986	0.474	0.723	0.481	0.630	0.720	0.045	972.455	3.168	0.872
1987	0.593	1.998	1.263	1.121	1.317	0.119	1606.928	3.276	1.366
1988	0.438	1.278	0.548	0.418	0.646	0.031	1046.086	3.020	0.840
1989	0.600	2.421	1.537	1.203	1.451	0.145	1459.666	3.473	1.373
1990	1.203	4.053	2.969	1.579	1.881	0.481	1676.423	3.376	2.005
1991	0.563	1.652	1.247	0.427	0.582	0.164	1009.678	3.187	0.942
MEAN	0.742	2.593	1.850	1.046	1.276	0.249	1390.104	3.236	1.403
TN									
1984	2.914	24.650	20.450	6.740	9.516	6.196	1702.139	11.867	8.269
1985	1.704	15.050	13.080	4.269	6.548	3.090	1535.799	10.682	5.980
1986	1.503	12.330	9.410	3.618	4.243	2.660	940.040	10.338	5.077
1987	3.592	17.210	12.610	4.963	5.971	3.750	1553.364	11.436	7.192
1988	0.967	17.160	14.250	3.285	3.977	2.742	1011.217	9.900	5.103
1989	1.277	23.520	20.030	5.152	6.373	4.356	1411.011	12.643	6.035
1990	1.679	21.220	20.350	5.817	7.765	4.528	1620.542	11.966	6.505
1991	1.088	11.140	8.107	3.594	4.292	3.247	976.022	10.157	4.406
MEAN	1.841	17.785	14.786	4.680	6.085	3.821	1343.767	11.124	6.071
PO4									
1984	0.010	1.015	1.040	0.182	0.308	0.423	58.694	0.435	0.326
1985	0.005	1.374	1.009	0.149	0.159	0.160	52.959	0.397	0.287
1986	0.001	1.045	0.752	0.091	0.086	0.176	32.415	0.409	0.235
1987	0.002	1.464	1.135	0.147	0.169	0.285	53.564	0.426	0.307
1988	0.001	1.425	1.372	0.061	0.077	0.089	34.870	0.387	0.265
1989	0.003	2.093	1.992	0.130	0.187	0.357	48.656	0.457	0.330
1990	0.012	1.631	1.393	0.205	0.245	0.389	55.881	0.442	0.326
1991	0.003	0.717	0.527	0.118	0.066	0.273	33.656	0.412	0.225
MEAN	0.005	1.345	1.153	0.135	0.162	0.269	46.337	0.421	0.288
ORGP									
1984	0.030	1.802	1.328	0.377	0.337	0.200	88.042	0.474	0.301
1985	0.020	0.608	0.481	0.181	0.179	0.071	79.438	0.439	0.161
1986	0.010	0.201	0.129	0.117	0.103	0.012	48.623	0.453	0.094
1987	0.013	0.559	0.338	0.210	0.188	0.032	80.346	0.468	0.154
1988	0.009	0.358	0.147	0.075	0.092	0.008	52.304	0.431	0.094
1989	0.014	0.677	0.412	0.225	0.207	0.039	72.983	0.496	0.159
1990	0.035	1.138	0.797	0.298	0.269	0.131	83.821	0.482	0.231
1991	0.013	0.462	0.333	0.077	0.083	0.044	50.484	0.455	0.103
MEAN	0.018	0.726	0.496	0.195	0.182	0.067	69.505	0.462	0.162

## Segment 200

Segment	-----Pervious-----							<-----Impervious----->		Total Load
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES		
TP										
1984	0.040	2.817	2.368	0.558	0.645	0.623	293.472	0.909	0.674	
1985	0.025	1.982	1.490	0.331	0.338	0.232	264.793	0.836	0.491	
1986	0.011	1.246	0.881	0.208	0.189	0.189	162.076	0.862	0.356	
1987	0.016	2.023	1.473	0.357	0.357	0.317	267.821	0.894	0.505	
1988	0.010	1.783	1.519	0.137	0.169	0.098	174.348	0.818	0.387	
1989	0.017	2.770	2.404	0.355	0.394	0.397	243.278	0.953	0.529	
1990	0.047	2.769	2.189	0.503	0.514	0.520	279.404	0.924	0.602	
1991	0.016	1.178	0.860	0.194	0.149	0.317	168.280	0.867	0.356	
MEAN	0.023	2.071	1.648	0.330	0.344	0.336	231.684	0.883	0.488	
BOD										
1984	11.932	144.000	66.900	10.410	19.080	19.830	4108.612	26.820	20.921	
1985	8.383	58.800	32.100	5.370	10.140	9.750	3707.101	24.840	12.268	
1986	5.249	15.150	7.890	3.390	5.820	1.779	2269.063	25.620	6.727	
1987	6.283	45.600	20.160	5.910	10.650	4.470	3749.498	26.490	10.566	
1988	4.759	26.340	11.040	2.379	5.220	1.974	2440.868	24.420	7.074	
1989	6.214	57.300	28.140	6.330	11.730	6.240	3405.888	28.080	11.397	
1990	9.549	111.000	50.700	8.220	15.210	16.620	3911.653	27.300	17.299	
1991	5.747	32.100	15.120	2.451	4.710	4.140	2355.914	25.770	8.106	
MEAN	7.265	61.286	29.006	5.558	10.320	8.100	3243.574	26.168	11.795	
SED										
1984	0.082	1.920	1.180	0.274	0.280	0.275	0.000	0.000	0.247	
1985	0.045	0.640	0.429	0.131	0.133	0.102	0.000	0.000	0.105	
1986	0.003	0.215	0.116	0.083	0.074	0.019	0.000	0.000	0.037	
1987	0.012	0.598	0.304	0.151	0.149	0.051	0.000	0.000	0.083	
1988	0.001	0.380	0.134	0.053	0.065	0.016	0.000	0.000	0.034	
1989	0.014	0.715	0.370	0.163	0.168	0.060	0.000	0.000	0.094	
1990	0.137	1.200	0.701	0.215	0.222	0.177	0.000	0.000	0.212	
1991	0.015	0.489	0.296	0.052	0.052	0.063	0.000	0.000	0.054	
MEAN	0.039	0.770	0.441	0.140	0.143	0.095	0.000	0.000	0.108	

PERCENT OF TOTAL LOAD CONTRIBUTED FROM EACH LAND USE/SOURCE IN SHENANDOAH BASIN

Segment 190

	-----Pervious-----						-----Impervious-----		Atmos	Point	Septic	Total
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Dep	Source	Load	Load
NH3												
1984	2.96	4.75	11.66	8.88	1.69	4.29	4.95	2.21	0.37	58.24	0.00	100.00
1985	2.65	2.41	4.00	7.63	1.65	3.06	6.68	2.72	0.42	68.75	0.00	100.00
1986	1.77	2.90	5.15	3.63	0.63	1.72	4.08	2.59	0.27	77.28	0.00	100.00
1987	2.38	3.56	6.57	7.02	1.53	2.80	5.66	2.58	0.41	67.51	0.00	100.00
1988	1.24	2.29	4.69	3.03	0.51	1.30	3.99	2.48	0.30	80.15	0.00	100.00
1989	2.17	4.74	8.44	9.44	1.37	7.33	6.08	3.30	0.52	56.60	0.00	100.00
1990	2.46	4.28	8.62	8.42	1.69	3.52	6.08	2.95	0.44	61.56	0.00	100.00
1991	2.79	3.30	5.84	7.91	1.20	3.78	5.65	2.88	0.41	66.25	0.00	100.00
MEAN	2.33	3.60	7.13	7.12	1.32	3.55	5.39	2.69	0.39	66.45	0.00	100.00
NO3												
1984	16.53	7.36	14.83	19.64	10.67	12.06	0.51	2.63	0.44	1.88	13.46	100.00
1985	10.69	8.65	17.66	20.28	10.82	9.80	0.61	2.82	0.47	2.02	16.20	100.00
1986	10.91	7.87	14.19	21.19	7.68	9.18	0.46	3.70	0.43	2.35	22.04	100.00
1987	13.40	7.82	14.26	22.88	9.40	11.27	0.55	2.90	0.45	1.98	15.09	100.00
1988	6.34	9.62	18.70	20.53	7.18	10.01	0.47	3.43	0.44	2.31	20.98	100.00
1989	6.80	9.92	20.89	22.64	9.25	11.87	0.49	2.87	0.42	1.49	13.35	100.00
1990	5.48	9.86	21.38	22.02	9.78	10.85	0.50	2.90	0.44	1.68	15.10	100.00
1991	7.89	8.14	16.01	23.36	9.29	10.88	0.50	3.16	0.45	2.00	18.31	100.00
MEAN	9.93	8.66	17.36	21.58	9.41	10.88	0.51	3.00	0.44	1.92	16.29	100.00
ORGN												
1984	24.38	4.11	8.52	15.42	8.40	5.04	26.94	2.34	0.07	4.78	0.00	100.00
1985	24.38	3.53	7.56	12.29	7.05	4.82	32.51	2.59	0.07	5.21	0.00	100.00
1986	25.21	1.81	3.24	11.91	4.03	1.67	37.13	5.67	0.12	9.22	0.00	100.00
1987	22.13	4.65	9.05	12.74	7.55	4.90	30.78	2.76	0.07	5.38	0.00	100.00
1988	24.45	2.60	4.82	8.52	3.18	1.13	38.54	5.34	0.12	11.27	0.00	100.00
1989	23.92	2.63	4.83	15.52	6.38	2.92	34.27	3.27	0.08	6.19	0.00	100.00
1990	24.53	3.60	7.39	13.02	7.39	4.78	30.27	2.98	0.08	5.95	0.00	100.00
1991	23.08	3.27	5.96	15.28	5.55	2.46	32.72	3.81	0.09	7.80	0.00	100.00
MEAN	23.93	3.47	6.89	13.47	6.67	3.87	31.97	3.27	0.08	6.39	0.00	100.00
TN												
1984	16.20	5.97	12.56	16.43	8.27	8.55	7.61	2.50	0.32	14.71	6.89	100.00
1985	13.41	6.09	12.37	15.86	8.14	7.21	9.33	2.79	0.35	15.86	8.58	100.00
1986	11.74	5.50	9.89	15.21	5.28	5.90	7.39	3.89	0.33	22.54	12.32	100.00
1987	13.84	6.19	11.45	17.16	7.43	7.93	8.41	2.84	0.34	16.41	7.99	100.00
1988	8.76	6.46	12.57	13.90	4.76	6.12	7.49	3.62	0.34	24.31	11.65	100.00
1989	10.30	7.32	14.95	18.80	7.23	9.01	8.21	3.10	0.36	12.94	7.78	100.00
1990	10.31	7.26	15.50	17.38	7.79	7.99	8.12	2.98	0.35	13.93	8.38	100.00
1991	10.90	6.07	11.69	18.62	6.89	7.50	8.10	3.32	0.36	16.23	10.31	100.00
MEAN	12.20	6.39	12.78	16.81	7.17	7.70	8.12	3.06	0.35	16.52	8.90	100.00
PO4												
1984	2.57	5.01	14.22	7.92	4.91	9.55	3.97	1.36	0.07	50.43	0.00	100.00
1985	1.74	6.88	11.16	9.80	3.87	6.99	4.53	1.40	0.07	53.56	0.00	100.00
1986	0.70	5.20	9.38	6.66	1.32	4.39	3.44	2.04	0.08	66.79	0.00	100.00
1987	2.48	6.81	12.20	9.36	3.86	8.59	3.97	1.39	0.07	51.27	0.00	100.00
1988	0.94	6.57	13.80	3.46	1.02	2.41	3.72	1.99	0.08	66.03	0.00	100.00
1989	2.26	10.73	21.04	10.90	3.28	13.60	4.58	1.73	0.08	31.81	0.00	100.00
1990	2.55	9.60	18.10	13.66	4.48	9.79	4.67	1.81	0.09	35.26	0.00	100.00
1991	2.13	6.11	11.56	12.42	2.88	13.59	4.52	2.04	0.09	44.66	0.00	100.00
MEAN	2.00	7.13	14.06	9.36	3.39	8.79	4.19	1.67	0.08	49.33	0.00	100.00
ORGP												
1984	4.40	8.65	17.23	22.06	9.09	10.24	10.20	2.53	0.35	15.24	0.00	100.00
1985	4.45	7.88	16.25	18.42	8.04	10.60	12.97	2.95	0.41	18.04	0.00	100.00
1986	4.68	4.13	7.11	18.35	4.72	3.75	15.21	6.63	0.67	34.72	0.00	100.00
1987	4.17	9.66	18.08	17.95	8.04	9.90	11.47	2.94	0.37	17.42	0.00	100.00
1988	4.62	5.66	10.08	12.24	3.55	2.37	15.06	5.97	0.64	39.79	0.00	100.00
1989	5.16	6.61	11.66	26.25	8.19	7.21	15.41	4.20	0.52	14.78	0.00	100.00
1990	5.19	8.37	16.53	20.42	8.79	10.94	12.60	3.54	0.46	13.15	0.00	100.00
1991	4.75	7.66	13.44	24.39	6.67	5.61	13.77	4.58	0.55	18.60	0.00	100.00
MEAN	4.64	7.78	14.84	20.38	7.65	8.46	12.84	3.75	0.46	19.20	0.00	100.00

## Segment 190

	-----Pervious-----						-----Impervious-----		Atmos	Point	Septic	Total
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Dep	Source	Load	Load
TP												
1984	3.05	5.98	14.43	12.36	6.07	9.22	11.79	1.69	0.16	35.25	0.00	100.00
1985	2.49	6.72	12.02	11.88	4.94	7.66	13.83	1.80	0.17	38.49	0.00	100.00
1986	1.61	4.63	8.28	9.04	2.05	3.97	12.08	3.01	0.21	55.12	0.00	100.00
1987	2.87	7.30	13.34	11.54	4.96	8.48	12.27	1.80	0.16	37.24	0.00	100.00
1988	1.81	5.92	11.98	5.46	1.60	2.25	12.70	2.87	0.22	55.20	0.00	100.00
1989	2.92	8.76	16.81	14.49	4.44	10.78	14.68	2.31	0.20	24.61	0.00	100.00
1990	3.25	8.52	16.32	14.96	5.60	9.49	13.95	2.26	0.21	25.45	0.00	100.00
1991	2.78	6.16	11.32	15.21	3.84	10.19	14.07	2.68	0.23	33.52	0.00	100.00
MEAN	2.68	6.86	13.38	12.13	4.48	8.11	13.14	2.20	0.19	36.84	0.00	100.00
BOD												
1984	28.98	10.76	15.12	9.50	8.15	11.91	7.54	2.27	0.00	5.78	0.00	100.00
1985	28.93	11.93	17.24	7.47	6.58	11.41	8.75	2.41	0.00	5.28	0.00	100.00
1986	36.56	5.30	7.03	8.81	4.56	5.33	12.12	6.41	0.00	13.88	0.00	100.00
1987	23.70	14.10	18.68	7.55	6.99	11.35	8.22	2.55	0.00	6.89	0.00	100.00
1988	31.72	7.61	12.92	6.20	3.41	4.01	11.92	5.73	0.00	16.48	0.00	100.00
1989	30.05	9.27	13.16	10.34	6.57	8.49	10.19	3.37	0.00	8.56	0.00	100.00
1990	26.37	12.21	17.04	7.87	6.89	11.25	8.15	2.78	0.00	7.44	0.00	100.00
1991	28.40	11.04	13.19	9.98	5.70	7.09	9.71	3.92	0.00	10.95	0.00	100.00
MEAN	28.48	10.97	15.21	8.53	6.55	9.79	9.06	3.21	0.00	8.21	0.00	100.00
SED												
1984	16.49	12.77	21.34	22.93	7.16	19.31	0.00	0.00	0.00	0.00	0.00	100.00
1985	14.46	12.94	22.36	21.29	6.82	22.12	0.00	0.00	0.00	0.00	0.00	100.00
1986	16.14	11.71	16.86	35.96	5.70	13.63	0.00	0.00	0.00	0.00	0.00	100.00
1987	16.49	14.87	23.30	19.40	6.59	19.35	0.00	0.00	0.00	0.00	0.00	100.00
1988	21.76	16.38	24.37	24.11	3.96	9.42	0.00	0.00	0.00	0.00	0.00	100.00
1989	17.53	11.31	16.84	31.38	6.77	16.20	0.00	0.00	0.00	0.00	0.00	100.00
1990	19.59	12.18	20.29	21.01	6.73	20.21	0.00	0.00	0.00	0.00	0.00	100.00
1991	16.25	13.72	20.18	30.43	5.75	13.68	0.00	0.00	0.00	0.00	0.00	100.00
MEAN	16.99	13.11	20.98	24.07	6.56	18.31	0.00	0.00	0.00	0.00	0.00	100.00

## Segment 200

	<-----Pervious----->						<-----Impervious----->		Atmos	Point	Septic	Total
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Dep	Source	Load	Load
<b>NH3</b>												
1984	3.41	5.09	6.22	8.60	1.18	3.74	4.68	1.91	0.51	64.65	0.00	100.00
1985	2.30	2.52	2.40	5.92	0.81	1.75	4.92	1.96	0.47	76.96	0.00	100.00
1986	1.65	4.36	4.52	3.65	0.53	1.88	3.20	1.83	0.36	77.98	0.00	100.00
1987	2.19	4.07	4.34	5.71	0.80	1.96	4.93	2.05	0.50	73.44	0.00	100.00
1988	1.27	3.33	4.35	3.80	0.47	1.39	3.33	1.79	0.39	79.91	0.00	100.00
1989	2.60	5.91	7.04	9.97	1.26	4.56	6.54	3.54	0.86	57.70	0.00	100.00
1990	3.04	5.78	7.73	10.64	1.57	3.59	7.35	3.10	0.75	56.43	0.00	100.00
1991	2.87	3.70	3.74	7.23	0.75	3.39	5.19	2.68	0.61	69.83	0.00	100.00
MEAN	2.39	4.27	4.95	6.71	0.90	2.67	4.86	2.25	0.53	70.42	0.00	100.00
<b>NO3</b>												
1984	18.91	9.04	10.95	22.23	8.14	11.57	0.43	2.08	0.56	0.72	15.37	100.00
1985	13.27	9.60	12.31	21.79	8.42	8.53	0.54	2.57	0.68	1.01	21.27	100.00
1986	17.64	8.48	9.40	22.36	6.08	8.45	0.36	2.68	0.57	0.99	23.00	100.00
1987	34.32	7.65	8.12	18.35	5.20	7.81	0.39	1.96	0.49	0.69	15.02	100.00
1988	8.82	12.66	15.44	21.13	5.72	8.94	0.38	2.51	0.59	0.94	22.86	100.00
1989	8.76	13.24	16.63	22.13	6.54	10.48	0.42	2.58	0.61	0.71	17.90	100.00
1990	6.09	10.99	16.01	24.82	8.17	10.74	0.50	2.57	0.64	0.75	18.75	100.00
1991	9.39	8.20	8.47	25.67	7.08	10.98	0.41	2.89	0.69	0.97	25.28	100.00
MEAN	15.62	9.94	12.14	22.10	6.92	9.70	0.43	2.43	0.60	0.83	19.29	100.00
<b>ORGN</b>												
1984	27.58	7.31	8.02	20.31	5.34	3.34	24.59	2.04	0.10	1.38	0.00	100.00
1985	29.65	3.85	4.53	15.61	4.45	1.83	34.78	2.97	0.14	2.23	0.00	100.00
1986	28.64	2.20	2.08	17.11	4.36	0.54	36.39	5.23	0.20	3.27	0.00	100.00
1987	22.89	3.88	3.49	19.44	5.10	0.91	38.40	3.45	0.15	2.31	0.00	100.00
1988	27.44	4.03	2.46	11.80	4.06	0.39	40.66	5.18	0.22	3.77	0.00	100.00
1989	22.99	4.67	4.22	20.73	5.58	1.11	34.68	3.64	0.15	2.19	0.00	100.00
1990	31.62	5.35	5.59	18.65	4.96	2.51	27.29	2.42	0.11	1.50	0.00	100.00
1991	31.50	4.65	5.00	10.74	3.27	1.82	34.97	4.87	0.20	2.98	0.00	100.00
MEAN	27.83	4.89	4.97	17.64	4.81	1.86	32.32	3.32	0.14	2.19	0.00	100.00
<b>TN</b>												
1984	18.56	7.90	9.34	19.30	6.08	7.85	6.72	2.07	0.43	13.56	8.20	100.00
1985	15.01	6.67	8.26	16.90	5.79	5.42	8.38	2.57	0.51	19.16	11.34	100.00
1986	15.59	6.43	7.00	16.87	4.42	5.49	6.04	2.93	0.46	21.42	13.36	100.00
1987	26.31	6.34	6.62	16.33	4.39	5.46	7.05	2.29	0.43	15.35	9.43	100.00
1988	9.98	8.91	10.54	15.24	4.12	5.63	6.47	2.79	0.48	22.54	13.29	100.00
1989	11.14	10.32	12.53	20.22	5.58	7.56	7.63	3.01	0.55	10.22	11.23	100.00
1990	13.59	8.64	11.81	21.16	6.31	7.29	8.13	2.65	0.50	9.48	10.42	100.00
1991	13.01	6.70	6.94	19.31	5.15	7.72	7.23	3.32	0.58	14.64	15.39	100.00
MEAN	15.97	7.76	9.19	18.25	5.30	6.59	7.22	2.64	0.49	15.42	11.17	100.00
<b>PO4</b>												
1984	1.67	8.26	12.05	13.20	5.00	13.60	5.88	1.92	0.16	38.26	0.00	100.00
1985	1.00	12.66	13.25	12.31	2.92	5.84	6.01	1.99	0.17	43.86	0.00	100.00
1986	0.29	11.77	12.07	9.14	1.93	7.85	4.50	2.50	0.17	49.79	0.00	100.00
1987	0.43	12.61	13.93	11.34	2.91	9.72	5.69	1.99	0.16	41.19	0.00	100.00
1988	0.20	14.25	19.54	5.47	1.53	3.53	4.29	2.10	0.16	48.92	0.00	100.00
1989	0.51	16.80	22.78	9.29	3.00	11.34	4.81	1.99	0.15	29.31	0.00	100.00
1990	1.87	13.25	16.13	14.90	3.97	12.51	5.59	1.95	0.16	29.67	0.00	100.00
1991	0.63	8.43	8.83	12.38	1.55	12.69	4.87	2.63	0.20	47.77	0.00	100.00
MEAN	0.87	12.38	15.11	11.13	2.98	9.80	5.25	2.10	0.17	40.19	0.00	100.00
<b>ORGP</b>												
1984	5.20	15.88	16.67	29.66	5.93	6.98	9.56	2.27	0.53	7.32	0.00	100.00
1985	6.51	10.03	11.31	26.75	5.90	4.66	16.16	3.94	0.90	13.86	0.00	100.00
1986	5.52	5.67	5.17	29.48	5.77	1.37	16.86	6.92	1.28	21.97	0.00	100.00
1987	4.47	9.60	8.27	32.25	6.45	2.17	17.00	4.37	0.93	14.49	0.00	100.00
1988	5.25	10.14	5.94	19.07	5.21	0.93	18.24	6.63	1.35	27.24	0.00	100.00
1989	4.49	11.24	9.75	33.43	6.87	2.59	14.93	4.48	0.91	11.31	0.00	100.00
1990	7.98	13.05	13.03	30.52	6.15	5.96	11.85	3.01	0.66	7.81	0.00	100.00
1991	6.65	11.87	12.20	17.61	4.27	4.45	15.99	6.36	1.29	19.30	0.00	100.00
MEAN	5.83	11.86	11.54	28.49	5.95	4.36	14.00	4.11	0.87	13.01	0.00	100.00

## Segment 200

	<-----Pervious----->					<-----Impervious----->			Atmos	Point	Septic	Total
	FOR	HTC	LTC	PAS	URB	HAY	ANML	RES	Dep	Source	Load	Load
TP												
1984	3.13	11.07	13.26	19.61	5.06	9.68	14.21	1.94	0.31	21.75	0.00	100.00
1985	2.71	10.69	11.45	15.94	3.64	4.94	17.59	2.45	0.40	30.19	0.00	100.00
1986	1.65	9.27	9.35	13.84	2.80	5.55	14.86	3.49	0.45	38.72	0.00	100.00
1987	1.62	10.60	11.00	16.74	3.74	6.58	17.29	2.55	0.38	29.48	0.00	100.00
1988	1.41	12.21	14.82	8.36	2.31	2.64	14.71	3.04	0.44	40.09	0.00	100.00
1989	1.67	13.86	17.15	15.87	3.94	7.86	15.00	2.59	0.37	21.69	0.00	100.00
1990	4.07	12.17	13.71	19.76	4.51	9.05	15.13	2.21	0.34	19.05	0.00	100.00
1991	2.32	8.77	9.13	12.94	2.22	9.33	15.44	3.51	0.50	35.85	0.00	100.00
MEAN	2.45	11.25	12.76	16.04	3.73	7.23	15.51	2.61	0.39	28.03	0.00	100.00
BOD												
1984	30.04	18.23	12.07	11.78	4.82	9.94	6.41	1.85	0.00	4.88	0.00	100.00
1985	35.98	12.70	9.87	10.36	4.37	8.33	9.85	2.91	0.00	5.60	0.00	100.00
1986	41.10	5.97	4.43	11.93	4.57	2.77	11.01	5.48	0.00	12.76	0.00	100.00
1987	31.32	11.43	7.20	13.24	5.33	4.43	11.58	3.61	0.00	11.86	0.00	100.00
1988	35.43	9.86	5.89	7.96	3.90	2.92	11.26	4.97	0.00	17.80	0.00	100.00
1989	28.72	13.31	9.32	13.15	5.44	5.74	9.75	3.55	0.00	11.02	0.00	100.00
1990	29.07	17.00	11.06	11.25	4.65	10.07	7.38	2.27	0.00	7.26	0.00	100.00
1991	37.33	10.49	7.04	7.16	3.07	5.35	9.48	4.57	0.00	15.49	0.00	100.00
MEAN	32.45	13.77	9.29	11.16	4.63	7.20	8.98	3.19	0.00	9.38	0.00	100.00
SED												
1984	17.55	20.57	18.02	26.24	5.99	11.66	0.00	0.00	0.00	0.00	0.00	100.00
1985	22.32	16.08	15.36	29.42	6.67	10.14	0.00	0.00	0.00	0.00	0.00	100.00
1986	4.40	15.27	11.74	52.62	10.54	5.43	0.00	0.00	0.00	0.00	0.00	100.00
1987	7.68	19.16	13.89	43.25	9.53	6.49	0.00	0.00	0.00	0.00	0.00	100.00
1988	2.24	30.03	15.09	37.48	10.25	4.92	0.00	0.00	0.00	0.00	0.00	100.00
1989	7.59	20.20	14.90	41.15	9.47	6.71	0.00	0.00	0.00	0.00	0.00	100.00
1990	34.11	15.02	12.50	24.06	5.55	8.77	0.00	0.00	0.00	0.00	0.00	100.00
1991	14.86	24.03	20.72	23.01	5.08	12.30	0.00	0.00	0.00	0.00	0.00	100.00
MEAN	18.82	18.84	15.39	30.70	6.98	9.25	0.00	0.00	0.00	0.00	0.00	100.00

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<b>13. ABSTRACT (Maximum 200 words)</b> <p>The focus of this research was to improve the overall utility of the Chesapeake Bay Watershed Model, based on the U.S. Environmental Protection Agency Hydrologic Simulation Program-Fortran model, as a planning tool for comprehensive watershed planning and assessment. The Chesapeake Bay Watershed Model is a unique state-of-the-art watershed modeling capability that includes detailed soil process simulation for agricultural areas, linked to an instream water quality and nutrient model capable of representing comprehensive point and nonpoint pollutant loadings for the entire 68,000-square mile drainage area of the Chesapeake Bay.</p> <p>The specific improvements recommended and tasks performed in this effort included development of nutrient balances for nonagricultural land uses; testing of the application procedures for forest, pasture, and urban land uses; and application of the enhanced model to the Shenandoah Subbasin within the Chesapeake Bay watershed to assess load contributions and impacts of the model refinements. The real benefits of the current refinement phase of the Chesapeake Bay Program Watershed Model are realized from the extension of the nutrient balance approach to all major land use (except urban, in the simulations) and the utility of this approach for nutrient management.</p> <p style="text-align: right;">(Continued)</p>				
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### **13. (Concluded).**

Recommendations presented for consideration of future refinements to the Watershed Model include the following:

- Finer segmentation for all stream reaches for better process representation.
- More consistent approach to organics and biochemical oxygen demand loadings for all land uses.
- Reevaluation of the representation of septic system loads.
- Further investigation and data review for the algal simulation—benthic algae and phytoplankton.
- Division of the lumped urban land use into identifiable urban categories for AGCHEM simulation.
- Simulation of individual crops and elimination of the “composite crop” representation.
- Review of nutrient application rates and procedures.
- Extension of the forest nitrogen simulation procedures to include phosphorus (P) simulation so that P mass balance procedures can be applied to all land uses.